NASA CR-159,329

NASA Contractor Report 159329

NASA-CR-159329

19800020847

COMPUTATION OF SPANWISE DISTRIBUTION OF
CIRCULATION AND LIFT COEFFICIENT FOR FLAPPED
WINGS OF ARBITRARY PLANFORM

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NASA Contract NAS1-15249
August 1980

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INTRODUCTION

Wing tip vortices have long been discussed as a primary factor in determining the distribution pattern and swath widths of materials ejected from agricultural aircraft. Some analytic work has been conducted to determine the effect of span loading on distribution pattern, starting with Wilmer Reed in 1954. (NACA TR #1196, 1953). Thousands of distribution patterns have been measured by researchers and many attempts have been made to modify the pattern of wing tip vortices but none of this work has provided a basis for altering either agricultural airplane design or agricultural airplane operations.

A quantitative assessment of the effect of span loading, both in magnitude and pattern, suitable for use in the field or by aircraft designers or modifiers appears to be necessary to permit decisions to be made with regard to airplane geometric characteristics or airplane flight operations. The advent of programmable calculators and microprocessor computers makes it possible to perform calculations which, up to this time, have been either difficult or impossible because of complexity and length. Accordingly the procedure for calculating span wise load distribution as described in NACA Technical Report 1071 has been programmed on a programmable calculator, the Hewlett Packard HP-97, as well as in BASIC Lanugage. The HP-97 and microprocessors which use BASIC Language are readily available and these programs will make it possible for either an airplane designer or airplane operator to study the effects of span loading on either design or operation.

The procedure of computing a span loading as given in NACA Technical Report 1071 has been reduced to a series of tables and charts so that the user need only to insert the geometric characteristics of his wings, together with the operating specifications of his airplane, and a span loading for his particular wing can be developed. The use of these programs, in conjunction with ASAE Paper #AA 79-001 will enable operators and designers to explore design and operating parameters to determine whether changes or modifications are possible that would materially or economically effect the swath width and distribution pattern.

SYMBOLS

A aspect ratio $\frac{b^2}{S}$

b span of the wing measured perpendicular to the plane of symmetry, feet

c wing chord, feet

c_{av} mean wing chord $\frac{S}{b}$, feet

c_l local lift coefficient $\frac{\text{local lift}}{qc}$

C_L lift coefficient $\frac{\text{total lift}}{qS}$

C_{L_δ} rate of change of lift coefficient with flap deflection, per radian

C_{L_α} rate of change of lift coefficient with wing angle of attack, per radian

$\frac{c_l c}{C_L c_{av}}$ spanwise loading coefficient for unit lift coefficient $\frac{2AG}{C_L}$

G spanwise loading coefficient or dimensionless circulation $\frac{c_l c}{2b}$ or $\frac{\Gamma}{bV}$

SYMBOLS

G	spanwise loading coefficient per radian of flap deflection $\frac{G}{\delta_1}$
M	Mach number
m	arbitrary number of span stations
q	free-stream dynamic pressure, pounds per square foot
S	wing area, square feet
V	free-stream velocity, feet per second
W	airplane weight, lb
W/S	Wing loading, lb/ft^2
w	induced velocity, normal to the lifting surface positive for downwash, feet per second
x	longitudinal coordinate measured from the lateral plane through the quarter chord of the wing-root chord, feet
y	lateral coordinate measured from the wing-root perpendicular to the plane of symmetry, feet
α	wing angle of attack, radians

SYMBOLS

α_ν	section angle of attack at span station ν, radians
$\frac{d\alpha}{d\delta}$	lift-effectiveness parameter $\frac{C_{L_\delta}}{C_{L_\alpha}}$
β	compressibility parameter $\sqrt{1 - M^2}$
Γ	circulation, feet squared per second
δ	angle of deflection of flap. radians
η	dimensionless lateral coordinate $\frac{y}{b/2}$
η_f	dimensionless flap span on one wing panel, measured perpendicular to the plane of symmetry, from the wing root outboard for inboard flaps, and from the wing tip inboard for outboard flaps $\frac{\text{flap span}}{b/2}$
ρ	air density slugs/ft^3
k_ν	ratio of section lift-curve slope at span station ν to $\frac{2\pi}{\beta}$, both at the same Mach number
Λ_β	sweep angle of the wing quarter-chord line, positive for sweepback, degrees
λ	wing taper ratio $\frac{\text{tip chord}}{\text{root chord}}$

SYMBOLS

SUBSCRIPTS

f	pertaining to flaps
t	wing tip,
r	wing root
av	average or mean
1	denoting full wing-chord flaps $\frac{c_f}{c} = 1$
ν	pertaining to spanwise station

CONVERSION FACTORS

1 meter (M)	=	3.281 feet
1 sq. meter (M^2)	=	10.76 sq. feet
1 meter/sec.(M/sec.)	=	3.281 ft./sec.
1 meters/sec.^{2}(M/sec^2)	=	3.281 ft./sec.
1 Kilogram (Kg)	=	2.205 pounds
1 Kg/M^3	=	.2048 slugs/ft.^{3}
1 Newton/M^2	=	2.089×10^{-2} lb./ft.^{2}

COMPUTATION PROCEDURE

No attempt will be made to summarize the theory or analysis which is the base for computing a span load distribution as per NACA Technical Report No. 1071. Rather, a step-by-step procedure will be tabulated, which procedure has been programmed for machine calculation.

A. The first step is to determine a span loading coefficient, $G = \frac{c_1 \cdot c}{2b}$. This is a dimensionless factor which is specified per radian angle of attack (or flap deflection angle of one radian). This coefficient is also written as $\frac{G}{\delta_1} = \frac{\Gamma}{2b}$, from which it can be seen that:

$$\frac{c_1 \cdot c}{2b} = \frac{\Gamma}{bV}$$

$$\text{or } \Gamma = \frac{c_1 \cdot c}{2}$$

The value of G/δ_1 varies with span and is a function of wing aspect ratio, taper ratio, sweep and flap span. It can be computed from the simultaneous equations (4) of Technical Report No. 1071 but it has already been computed and plotted in Figure 4 of T.R. 1071 for a range of aspect ratios, sweep, taper ratios, and flap span. Two of these curves, Figures 4(c) and 4(d), for sweep angles of 0^o, have been used to read values of G/δ_1 for aspect ratios of 6, 8, and 10; taper ratios of .667 and 1.0; and flap spans of .195b, .556b, and 1.0b. These graphs appear as Figure 1 and Figure 2 of this report. G/δ_1 values were also read for outboard flap spans of .444b and .805b which are the complements of .195 and .556. These values are tabulated in Table I through Table V.

The first step in the computational procedure is therefore to read from Table I through Table V the appropriate values of G/δ_1 for the selected wing and flap span at each of the span stations.

B. The wing specifications of span, taper ratio, wing area, and section lift curve slope must be defined.

C. The wing or airplane operating conditions of wing loading, air density and speed, in proper units, must be stated.

D. Agricultural aircraft all operate at maximum airspeed less than 300 ft./ sec. No correction for Mach Number is therefore required.

E. The wing chord at the spanwise stations corresponding to values of G/δ_1 must be computed. For a given taper ratio , λ , the expressions for root and tip chord are:

$$c_r = \frac{2 \cdot S}{b\ (1+\lambda)}$$

$$c_t = \lambda \cdot c_r$$

The wing chord at any spanwise station, $\frac{y}{b/2}$, is:

$$c_y = c_r \left\{ 1 - \left[\frac{y}{b/2} (1-\lambda) \right] \right\}$$

F. Since $G/\delta_1 = \dfrac{c_1 \cdot c}{2b}$,

$$c_1 \cdot c = 2b\ (G/\delta_1)$$

$c_1 \cdot c$ is computed and the wing lift coefficient at station y is : $c_{1_y} = \dfrac{c_1 \cdot c}{c_y}$

G. If a wing operating lift coefficient is chosen, the flight speed is:

$$V = \sqrt{\frac{W/S}{(\rho/2)\ V^2}}$$

or

$$C_L = \frac{W/S}{(\rho/2)\ V^2}$$

H. The circulation, Γ, at each span station is:

$$\Gamma_y = \frac{c_{l_y}\ (\rho/2)\ S_y \cdot V^2}{\rho V} = \frac{c_{l_y} \cdot S_y \cdot V}{2}$$

and

$$\Gamma_y = \frac{c_{l_y} \cdot c_y \cdot \Delta_y \cdot V}{2}$$

A plot of Γ_y as a function of span will enable $\Delta\Gamma/\Delta y$ to be secured. In order to compare this value of shed vorticity with another wing, both values of must be computed at the same wing C_L.

I. The wing lift coefficient for α = 1 radian is computed as follows:

$$C_{L_1} = \frac{\sum \left(c_{l_y} \cdot c_y \cdot \Delta y\right)}{S}$$

The wing lift coefficient at any angle of attack is:

$$C_L = \frac{C_{L_1}}{57.3} \cdot \alpha$$

The section lift coefficient at any spanwise station for a given operating lift coefficient, $C_{L_{op}}$ is:

$$c_{l_{y_{op}}} = \frac{c_{l_{y_1}} \cdot c_{l_{op}}}{C_{L_1}}$$

J. Wing lift curve slope is:

$$\frac{dC_L}{d\alpha} = \frac{C_{L_1}}{57.3}$$

K. The local lift coefficient, c_y, at any span station ,y, is given by:

$$c_{l_y} = \frac{C_L \cdot c_{l_y}}{C_{L_1}}$$

H.P. 97 Program.

The Hewlett-Packard H.P. 97 programmable calculator is a small desk size unit which is programmed in its own machine language. 224 program steps are available with 26 storage registers. Programs are stored on small magnetic cards.

The Span loading analysis program is listed on pages 28 and 29 . Data entry instructions and program operating instructions are given in appendix A.

The program is run in two segments using the computation forms shown on pages 26 and 27 .

The first segment of the program computes the local wing chord at station y, ranging from root to tip, at span stations as identified from the appropriate Table I through V. The wing characteristics are summarized on the first computation page, following which G/δ_1 and y/b/2 values are listed in the first two columns. The value of Δy is the length of each span segment, entered in feet. Successive computations are performed to secure the chord length at the midpoint of each span segment. The output of the computer is illustrated on page 30 . The computed values of C_y are entered in column 5.

The second segment of the program uses computational chart II with the entries as shown on page 31 . The first run is an initializing run followed by sequence computation of circulation at each span station. A sample computer listing with indentifier code is shown on page 30 .

BASIC PROGRAM

The span loading analysis procedure has been programmed in BASIC language for a Rockwell AIM-65 microprocessor. This program should be adaptable to any of the currently available microprocessors although it should be carefully studied to see whether the syntax of this program is compatible with the microprocessor in question.

The parameters which describe the particular wing being studies, such as gross weight, wing area, lift coefficient (corresponding to the desired swath speed), air density, taper ratio, aspect ratio, flap span, and so forth, are entered manually into the program as per the program statements. If the value of X in statement 16 is input as zero the program computes the swath speed and lists this speed. Alternatively a value of 1.0 for X in statement 16 will cause the program to compute a flight lift coefficient based upon an input speed. In other words, a choice can be made of either selecting an operating lift coefficient and the speed will be computed and printed out or the swath speed can be input and the operating lift coefficient will be computed and printed out.

A twenty column listing gives sequential values of lift coefficient and circulation as a function of span position. Final output is the lift coefficient per radian for either angle of attack or flap deflection together with the lift curve slope of the particular wing. Additional wing geometries can be explored without changing airplane parameters by entering the wing geometry parameters in data statements 170, 171, 172, and 173. The numbers in these data statements are concurrent values of the span station and G/δ_1 factor. For the program as illustrated in Appendix B the first two numbers in statement 170 are actual illustrations of the G/δ_1 factor of .379 at a span station of .05. The numbers as actually illustrated in the listed program correspond to values for a wing with full span flaps, aspect ratio 8 and a taper ratio of .667. These values were taken from Table III. In summary, data statements 170 thru 173 are the tabular values of the span loading factor as read from table I-V.

The output of the BASIC program is a function of the printer being used with the microprocessor. A twenty column output listing is illustrated on page 34 (Appendix B).

Two versions of the BASIC span loading program were prepared. These are designated with file names of SPNLA and SPNLB respectively. They differ only in the manner in which variables are entered into the computer.

In SPNLA the airplane and operating parameters are written as program statements 17 through 24. This version of the program is useful when a large number of wings are to be compared for the same airplane parameters.

In SPNLB the airplane and operating parameters are entered as input statements 17 through 24. With this version of the BASIC program every variable must be entered each time the program is run but SPNLB gives more flexibility in parameter variation.

The output listing of both SPNLA and SPNLB are the same except for listing of input data. A sample output listing is shown on page 36.

WING ANALYSIS

A large number of wings, with parameters as tabulated in Tables VI, VII, and VIII, pages 21 thru 23, have been analyzed. Span loading curves for these wings have been prepared and are presented in Figures 3&4. These curves, or the listing from computer programs, can be used to compare span loadings for various wings at various operating conditions.

CONCLUDING REMARKS

Two programs, one for a programmable calculator and one written in BASIC for a microprocessor have been prepared to compute span loading analysis for wings of varying parameters. The span loading as computed by the procedures in this report can be used, in conjunction with reference 4 to evaluate the effect of span loading and its distribution upon the trajectory of particles discharged from any point along the wing span. By using the shed vorticity, as determined by the method as described in this report in conjunction with the dynamics of the discharge particles, a prediction of distribution pattern is possible.

REFERENCES

1. Akesson, Norman B.: Dispersion of Materials Released in the Wake of an Aircraft. ASAE Paper 77-1043, 1977.

2. Bragg, Michael B.: The Trajectory of a Liquid Droplet Injected into the wake of an Aircraft in Ground Effect. University of Illinois Technical Report AEE 77-7, May 1977.

3. DeYoung, John: Theoretical Symmetric Span Loading Due to Flap Deflection for Wings of Arbitrary Plan Form at Subsonic Speeds. NACA TR 1071, 1952.

4. Holmes, Bruce; Morris, Dava; and Razak, Kenneth: Data and Analysis Procedures for Improved Aerial Applications Mission Performance. ASAE Paper AA 79-001, Dec., 1979.

5. Razak, Kenneth: An Operations Analysis and Distributor Wing Experiment. Agricultural Aviation. International Agricultural Aviation Center, Cranfield, England, November 4, 1962, Volume 4, Number 4, pp. 118-130.

6. Reed, Wilmer H., III.: An Analytical Study of the Effect of Airplane Wake on the Lateral Dispersion of Aerial Sprays. NACA Report Number 1196, 1953.

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Table I
Values of span loading factor G/δ_1 from reference 3 for wings with inboard flaps, η_f =.195 b/2

TAPER RATIO=.667

STATION, %b/2	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO=10
.05	.26	.235	.21
.15	.225	.20	.175
.25	.14	.115	.09
.35	.085	.068	.05
.45	.06	.045	.03
.55	.035	.027	.02
.65	.02	.017	.015
.75	.016	.015	.015
.825	.013	.014	.015
.875	.010	.01	.01
.925	.01	.008	.007
.975	.01	.007	.005

TAPER RATIO=1.0

.05	.245	.215	.185
.15	.210	.185	.16
.25	.125	.102	.08
.35	.08	.065	.05
.45	.05	.04	.03
.55	.03	.025	.02
.65	.02	.017	.015
.75	.015	.015	.015
.825	.010	.012	.015
.875	.008	.009	.01
.925	.008	.008	.007
.975	.008	.007	.005

Table II
Values of span loading factor G/δ_1
from reference 3 for wings with
inboard flaps; $\eta_f = .556\ b/2$

TAPER RATIO=.667

STATION	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO =10
.05	.40	.343	.285
.15	.395	.340	.285
.25	.385	.332	.280
.35	.355	.302	.25
.45	.30	.255	.21
.55	.235	.192	.15
.65	.14	.113	.085
.75	.085	.065	.045
.825	.055	.042	.03
.875	.045	.035	.025
.925	.040	.030	.02
.975	.025	.022	.02
1.0	0		

TAPER RATIO=1.0

STATION	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO =10
.05	.375	.312	.25
.15	.37	.315	.26
.25	.36	.307	.255
.35	.33	.28	.23
.45	.29	.245	.20
.55	.235	.192	.15
.65	.13	.107	.085
.75	.06	.052	.045
.825	.03	.03	.03
.875	.025	.025	.025
.925	.025	.022	.02
.975	.025	.022	.02

Table III
Values of span loading factor G/δ_1
from reference 3 for wings with
full span flaps $\eta_f = 1.0\ b/2$

TAPER RATIO=0.667

	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO=10
.05	.445	.379	.313
.15	.442	.375	.307
.25	.433	.365	.296
.35	.419	.353	.286
.45	.40	.337	.274
.55	.378	.319	.259
.65	.347	.293	.238
.75	.31	.263	.216
.825	.265	.229	.192
.875	.225	.198	.170
.925	.186	.161	.135
.975	.107	.09	.073

TAPER RATIO=1.0

.05	.41	.345	.28
.15	.41	.345	.28
.25	.408	.343	.278
.35	.403	.338	.273
.45	.395	.33	.265
.55	.388	.322	.255
.65	.360	.303	.245
.75	.315	.273	.23
.825	.275	.24	.205
.875	.240	.21	.18
.925	.20	.173	.145
.975	.12	.10	.08

Table IV
Values of span loading factor G/δ_1 from reference 3 for wings with outboard flaps, $\eta_f = 0.805\ b/2$

TAPER RATIO=0.667

	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO =10
.05	.185	.144	.103
.15	.217	.175	.132
.25	.293	.25	.206
.35	.334	.285	.236
.45	.34	.292	.244
.55	.343	.292	.239
.65	.327	.276	.223
.75	.294	.248	.201
.825	.252	.215	.177
.875	.215	.188	.16
.925	.176	.153	.128
.975	.097	.083	.068

TAPER RATIO=1.0

.05	.165	.13	.095
.15	.20	.16	.12
.25	.283	.24	.20
.35	.323	.273	.223
.45	.345	.29	.235
.55	.358	.296	.235
.65	.340	.285	.23
.75	.30	.258	.215
.825	.265	.228	.19
.875	.232	.201	.17
.925	.192	.165	.138
.975	.112	.094	.075

Table V
Values of span loading factor, G/δ_1
from reference 3 for wings with
outboard flaps, $\eta_f = 0.444\ b/2$

TAPER RATIO=0.667

	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO=10
.05	.047	.039	.03
.15	.046	.035	.024
.25	.051	.035	.02
.35	.071	.053	.036
.45	.099	.084	.068
.55	.152	.134	.116
.65	.204	.177	.151
.75	.220	.193	.166
.825	.203	.184	.165
.875	.178	.163	.148
.925	.149	.137	.125
.975	.09	.076	.063

TAPER RATIO=1.0

.05	.035	.031	.028
.15	.038	.03	.023
.25	.05	.036	.023
.35	.073	.055	.038
.45	.103	.084	.065
.55	.16	.136	.113
.65	.218	.188	.158
.75	.225	.203	.18
.825	.213	.196	.178
.875	.193	.176	.158
.925	.163	.144	.125
.975	.103	.087	.07

TABLE VI

CHARACTERISTICS OF WINGS ANALYZED

WING	W/S (lb/Ft^2)	ASPECT RATIO	TAPER RATIO	FLAP SPAN η_f	WING AREA (Ft^2)	WING SPAN (Ft)	WEIGHT (lbs)
N1	25	6.04	1.0	None	326.6	44.417	8160
N2	25	8.0	1.0	None	326.6	51.116	8160
N3	25	10	1.0	None	326.6	57.149	8160
N4	25	6	.667	None	240	44'	6000
N5	25	8	.667	None	240	44'	6000
N6	25	10	.667	None	240	44'	6000
N7	25	6	.5	None	326.6	44.4'	8160
N8	25	8	.5	None	326.6	51.116'	8160
N9	25	10	.5	None	326.6	57.149'	8160
N10	25	8	1.0	None	450	60	11250
N11	25	7.5	.667	None	450	58.095	11250
N12	25	8	.667	None	450	60	11250
N13	25	8	1.0	* Inb=.556	326.6	51.116	8160
N14	15	8	1.0	Inb=.556	326.6	51.116	8160
N15	25	8	.667	Inb=.556	326.6	51.116	8160
N16	15	8	.667	Inb=.556	326.6	51.116	8160
N17	25	8	.5	Inb=.556	326.6	51.116	8160

* inboard of station η_f

TABLE VII

CHARACTERISTICS OF WINGS ANALYZED

WING	W/S (lb/ft^2)	ASPECT RATIO	TAPER RATIO	FLAP SPAN η_f	WING AREA (ft^2)	WING SPAN (ft)	WEIGHT (lbs)
N18	15	8	.5	Inb=.556	326.6	51.116	5000
N19	25	8	.667	Inb=.556	450	60	11250
N20	25	10	.667	None	450	67.082	11250
N21	25	8	.667	None	326.6	51.116	8160
N22	25	8	1.0	Inb=.195	326.6	51.116	8160
N23	25	8	.667	Inb=.195	326.6	51.116	8160
N24	25	8	1.0	Inb=.195	450	60	11250
N25	25	8	.667	Inb=.195	450	60	11250
N26	25	6	.667	None	326.6	44.417	8160
N27	25	10	.667	None	326.6	57.149	8160
N28	25	6	.667	None	450	51.962	11250
N29	25	8	1.0	* O.B.0.444	326.6	51.116	8160
N30	25	8	1.0	O.B.0.805	326.6	51.116	8160
N31	25	8	0.667	O.B.0.444	326.6	51.116	8160
N32	25	8	0.667	O.B.0.805	326.6	51.116	8160
N33	25	8	1.0	O.B.0.444	450	60	11250
N34	25	8	1.0	O.B.0.805	450	60	11250

* outboard of station η_f

TABLE VIII

CHARACTERISTICS OF WINGS ANALYZED

WING	W/S (lb/ft^2)	ASPECT RATIO	TAPER RATIO	FLAP SPAN η_f	WING AREA (ft^2)	WING SPAN (ft)	WEIGHT (lbs)
N35	25	8	0.667	O.B.0.444	450	60	11250
N36	25	8	0.667	O.B.0.805	450	60	11250
N37	30	8	.667	None	327	51.116	9810
N38	35	8	.667	None	327	51.116	11445
N39	40	8	.667	None	327	51.116	13080
N40	30	8	.667	Inb=.556	327	51.116	9810
N41	35	8	.667	Inb=.556	327	51.116	11445
N42	40	8	.667	Inb=.556	327	51.116	13080
N43	30	6	.667	None	327	44.3'	9810
N44	35	6	.667	None	327	44.3'	11445
N45	40	6	.667	None	327	44.3'	13080
N46	30	6	.667	Inb=.556	327	44.3'	9810
N47	35	6	.667	Inb=.556	327	44.3'	11445
N48	40	6	.667	Inb=.556	327	44.3'	13080

User Instructions

APPENDIX A
Hewelett Packard 97-7,
SPAN LOADING ANALYSIS

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
I	Enter Data	Reg			
	G/δ_1	0			
	Span Station, % $^b/_2$,	1			
	Δy, % $^b/_2$, decimal	2			
	P ⇄ S				
	Wing Span, b	0			
	Wing Area, S	1			
	Taper Ratio, λ	2			
	Gross Weight W	3			
	Air Density, ρ	4			
	Airplane C_L	5			
		6			
		7			
		8			
	Airplane Speed, ft./sec, input for				
	Constant C_L	9			
	P ⇄ S				
II	Press A for first run				
III	Enter data for 2nd run, yn				
	G/δ_1	0			
	yn	1			
	Δy	2			
	Press B				
IV	Repeat Step III. On last step				
	store 1 in Register I, Press B				
	Program prints out C_L as last item.				
V	STO first value of Δy in	1			
	$\Delta y/b/2$	2			
	P ⇄ S				
	$c_1 \times c_y$				
	P ⇄ S	8			
VI	Press C. Using same entries				
	press D.				
VII	Repeat VI for as many steps as nec-				
	essary. Last step should be y=1.0				
	& $c_1 \times c_y = 0$, last print-out will				
	be shed vorticity at tip of wing				

User Instructions

APPENDIX A (continued)
Hewelett Packard 97-7,
SPAN LOADING ANALYSIS

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
	DATA STORAGE			
REG				
1	G/δ_1 (From Tables I-V)			
2	$^y/\ b/2$	%		
3	Δy	FT.		
4				
5				
6				
7				
8				
9				
10				
A				
B				
C				
D				
E				
I				
10	Wing Span, Ft.	FT.		
11	Wing Area, $Ft.^2$	$FT.^2$		
12	Taper Ratio, $^{Ct}/Cr$, λ			
13	Weight, # lb	lb		
14	Air Density-Slugs/Cu. Ft. , ρ			
15	Wing C_L			
16	Cr	FT.		
17	Ct	FT.		
18	$c_{l_y} \times c_y$			
19	V	FT./SEC.		
	using W/S, ρ & C_L			

Hewlett Packard
H. P. 97

APPENDIX A (continued)

Date ________
Sheet ________

SPAN LOADING ANALYSIS

I. Wing, Airplane and Operating Data

Identification ________________________

			Register
Wing Span	________ ft.	________ m	____
Wing Area	________ sq.ft.	________ sq.m	____
Taper Ratio	________		____
Operating Weight	________ #	________ kg	____
Air Density	________ slugs/cu.ft.	________ kg/m^3	____
Wing C_L	________	(for C_L =constant)	____
Swath Speed	________ mph	________ Kphr	____
Root Chord	________ ft.	________ m	____
Tip Chord	________ ft.	________ m	____
Aspect Ratio	________		____

Flap:
Type ________________________
Chord ________ %, Span ________ %

$dC_L/d\alpha$ ________, $d\alpha/d\delta_f$ ________, Up to δ_f = ________

INPUT DATA, RUNS [A] & [B]

G/δ_1 Reg.0	y/b/2 Reg.1	Δ y Reg.2	Start Program	C_y
			[A]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	

PRINT REGISTERS

SPAN LOADING ANALYSIS, PART II	APPENDIX A (continued)	HEWLETT PACKARD H.P. 97

WING IDENTIFICATION____________________ SHEET__________

INPUT DATA, RUNS $\boxed{C}$ & $\boxed{D}$

$y/_{b/2}$ REG. 1	Δy REG. 2		$c_{l_y} \times c_y$ REG. 8		PRESS	Γ	$\Delta\Gamma$
		P⇄S		P⇄S	C		
	SAME ENTRIES				D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		

APPENDIX A (Continued)
PROGRAM LISTING H.P. 97-7
Span Loading Analysis

Step	Key Entry	Step	Key Entry
001	LBLA	055	0
002	DSP3	056	STOI
003	SPC	057	LBLB
004	SPC	058	RCL0
005	SPC	059	PRTX
006	P⇌S	060	P⇌S
007	RCL0	061	RCL0
008	PRTX	062	X
009	RCL1	063	2
010	PRTX	064	X
011	RCL2	065	PRTX
012	PRTX	066	STO8
013	RCL3	067	RCL2
014	PRTX	068	CHS
015	RCL4	069	1
016	PRTX	070	+
017	RCL5	071	P⇌S
018	PRTX	072	RCL1
019	RCL2	073	X
020	1	074	CHS
021	+	075	1
022	RCL0	076	+
023	X	077	P⇌S
024	1/X	078	RCL6
025	RCL1	079	X
026	X	080	PRTX
027	2	081	STOA
028	X	082	1/X
029	STO6	083	RCL8
030	PRTX	084	X
031	RCL2	085	P⇌S
032	X	086	STOB
033	PRTX	087	PRTX
034	STO7	088	RCL1
035	RCL3	089	P⇌S
036	RCL1	090	RCL0
037	÷	091	X
038	RCL4	092	2
039	÷	093	÷
040	RCL5	094	P⇌S
041	÷	095	PRTX
042	2	096	STOC
043	X	097	RCL2
044	√x	098	P⇌S
045	PRTX	099	RCL0
046	STO9	100	X
047	P⇌S	101	2
048	SPC	102	÷
049	SPC	103	RCLA
050	RCL1	104	X
051	PRTX	105	PRTX
052	SPC	106	STOD
053	0	107	RCL8
054	STOE	108	RCL0

PROGRAM LISTING
Span Loading Analysis

H.P. 97-7

Step	Key Entry
109	X
110	2
111	÷
112	P⇌S
113	RCL2
114	X
115	RCLE
116	+
117	STOE
118	PRTX
119	RCLI
120	X=0?
121	GTOE
122	RCLE
123	P⇌S
124	RCL1
125	÷
126	2
127	X
128	SPC
129	PRTX
130	P⇌S
131	STO3
132	LBLE
133	SPC
134	RTN
135	LBLC
136	RCL3
137	5
138	7
139	.
140	3
141	÷
142	STO4
143	PRTX
144	1
145	5
146	STOI
147	RCLi
148	RCL3
149	÷
150	STO5
151	PRTX
152	LBLD
153	P⇌S
154	RCL8
155	RCL9
156	X
157	2
158	÷
159	P⇌S
160	RCL5
161	X
162	STO6

Step	Key Entry
163	PRTX
164	STO8
165	RCL7
166	RCL8
167	-
168	PRTX
169	RCL9
170	+
171	STO9
172	RCL8
173	STO7
174	SPC
175	SPC
176	RCLI
177	X<0?
178	GTO1
179	R/S
180	LBL1
181	RTN
182	R/S

H.P. 97 COMPUTER LISTING CODE

Sample run for wing N-27 (See Table VII).

PART I

INPUT DATA

```
          CLRG
.313      STO0
.050      STO1
.100      STO2
          P⇄S
57.149    STO0
326.600   STO1
.667      STO2
8160.000  STO3
.002378   STO4
.807      STO5
          P⇄S
          GSBA
```

57.149	***	WING SPAN, FT
326.500	***	WING AREA, SQ FT
0.667	***	λ, TAPER RATIO
8160.000	***	GROSS WT., #
0.002	***	ρ = AIR DENSITY
0.807	**	WING C_L
6.856	***	C_r, ROOT CHORD
4.573	***	C_t, TIP CHORD
161.365	***	V, FT/SEC
0.050	***	SPAN STATION y/b/2
0.313	***	G/S, (REF 1071)
35.775	***	$C_\ell \times C_y$
6.742	***	C_y
5.306	***	$C_{\ell y}$
1.429	***	y, FT FROM ℄
19.266	***	Δ AREA, SQ. FT
102.226	***	($C_{\ell y}$ x Δ AREA)
.307	STO0	G/S, AT
.150	STO1	y/(b/2)
	GSBB	
0.307	***	G/S,
35.089	***	$C_\ell \times C_y$
6.514	***	C_y
5.387	***	$C_{\ell y}$
4.286	***	y, FT
18.613	***	Δ AREA
202.493	***	($C_{\ell y}$ x Δ AREA)
.296	STO0	COMPUTATION
.250	STO1	FOR NEXT
	GSBB	OUTBOARD
0.296	***	SPAN STATION
33.832	***	
6.286	***	
5.382	***	
7.144	***	
17.961		
299.166		

```
.286     STO0
.350     STO1
         GSBB
0.286    ***
32.689   ***
6.057    ***
5.397    ***
10.001   ***
17.309   ***
392.574  ***

.274     STO0
.450     STO1
         GSBB
0.274    ***
31.318   ***
5.829    ***
5.373    ***
12.859   ***
16.656   ***
482.063  ***

.259     STO0
.550     STO1
         GSBB
0.259    ***
29.603   ***
5.601    ***
5.286    ***
15.716   ***
16.004   ***
566.652  ***

.238     STO0
.650     STO1
         GSBB
0.238    ***
27.203   ***
5.372    ***
5.063    ***
18.573   ***
15.351   ***
644.383  ***

.216     STO0
.750     STO1
         GSBB
0.216    ***
24.680   ***
5.144    ***
4.798    ***
21.431
14.699
714.929
```

```
.192     STO0
.825     STO1
.050     STO2
         GSBE
0.192    ***
21.945   ***
4.973    ***
4.413    ***
23.574   ***
7.105    ***
746.283  ***

.170     STO0
.875     STO1
         GSBB
0.170    ***
19.431   ***
4.859    ***
3.999    ***
25.003   ***
6.942    ***
774.044  ***

.135     STO0
.925     STO1
         GSBB
0.135    ***
15.430   ***
4.745    ***
3.252    ***
26.431   ***
6.779    ***
796.089  ***

.073     STO0
.975     STO1
1.000    STO1
         GSBB
0.073    ***
8.344    ***
4.630    ***
1.802    ***
27.860   ***
6.616    ***
808.010  ***
4.948    ***
```

WING C_L AT α = 1 RADIAN

APPENDIX A (Continued)

H.P. 97 COMPUTER LISTING CODE

PART II

```
          PREG
0.073     0
0.975     1
0.050     2
4.948     3
0.000     4
0.000     5
0.000     6
0.000     7   -> INPUT DATA
0.000     8
0.000     9
4.630     A
1.802     B
27.860    C
6.616     D
808.010   E
1.000     I

          P⇄S
          PREG

57.149    0
726.600   1
0.667     2
6160.000  3
0.002     4
0.807     5
6.856     6
4.573     7
8.344     8
161.365   9
4.630     A
1.802     B
27.860    C
6.616     D
808.010   E
1.000     I

          P⇄S
.050      STO1   y OF MIDPOINT OF Δy
.100      STO2   Δy, % b/2
          P⇄S
35.775    STO8   Cey x Cy
          P⇄S
          GSBC
0.086     ***
0.163     ***
470.762   ***
-470.762  ***


          GSBD
470.762
0.000
```

```
.150      STO1
          P⇄S
35.089    STO8
          P⇄S
          GSBD
461.735   ***   ΔT AT y
9.027     ***   ΔT

.250      STO1
          P⇄S
33.832    STO8
          P⇄S
          GSBD
445.194   ***
16.541    ***

.350      STO1
          P⇄S
32.689    STO8
          P⇄S
          GSBD
430.154   ***
15.041    ***

.450      STO1
          P⇄S
31.318    STO8
          P⇄S
          GSBD
412.113   ***
18.041    ***

.550      STO1
          P⇄S
29.603    STO8
          P⇄S
          GSBD
389.545   ***
22.568    ***

.650      STO1
          P⇄S
27.203    STO8
          P⇄S
          GSBD
357.964
31.582
```

```
.750      STO1
          P⇄S
24.668    STO8
          P⇄S
          GSBD
324.869   ***
33.095    ***

.825      STO1
.050      STO2
          P⇄S
21.945    STO8
          P⇄S
          GSBD
288.774   ***
36.095    ***

.875      STO1
          P⇄S
19.431    STO8
          P⇄S
          GSBD
255.692   ***
33.082    ***

.925      STO1
          P⇄S
15.430    STO8
          P⇄S
          GSBD
203.043   ***
52.649    ***

.975      STO1
          P⇄S
8.344     STO8
          P⇄S
          GSBD
109.798   ***
93.244    ***

1.000     STO1
          P⇄S
0.000     STO8
          P⇄S
          GSBD
0.000     ***
109.798   ***
```

APPENDIX B

BASIC program for SPAN LOADING ANALYSIS

file name="SPNLA"

LIST

```
1        POKE 41993, 32
10       PRINT "1071 SPAN LOADING ANALYSIS"
11       DIM DELY (13), GDEL (13)
12       M=1
14       INPUT "FLAP SPAN =";FSP
16       INPUT "SPEED COMPUTATION=";X
17       VFPS=139
18       WT=6000
20       AREA=327
22       RHO=0.002378
24       CL=0.8
26       IF X=1 then 30
28       GOTO 36
30       VFPS= SQR (WT/ (AREA*RHO/2*CL))
32       PRINT "SPEED=";VFPS
34       GOTO 40
36       CL=WT/ (RHO/2*VFPS'2*AREA)
38       PRINT "LIFT COEFFICIENT=";CL
40       INPUT "SPAN=";SPAN
42       INPUT"TAPER RATIO=";TR
44       INPUT"ASPECT RATIO":ASPR
45       CR=(2*AREA)/(Span*(1+TR))
46       PRINT"CR=";CR
47       FOR I= 1 TO 13
49       READ DELY (I), GDEL (I)
50       NEXT I
51       DELY=DELY (M)
52       GDEL=GDEL (M)
53       K=1-DELY
54       IF K=0 THEN 80
62       CT=TR*CR
64       CY=CR*(1-(DELY*(1-TR)))
65       YCL=2*SPAN*GDEL/CY
66       IF DELY >0.75 THEN 69
67       YINC=0.1
68       GOTO 75
69       YINC=0.05
75       SMCL=SMCL+YCL*CY*YINC*SPAN
76       M=M+1
77       GOTO 51
80       RCL=SMCL/AREA
82       MULT=CL/RCL
84       SLC=RCL/57.3
90       M=1
```

Page two

```
91    DELY=DELY (M)
92    GDEL=GDEL (M)
102   K=1-DELY
104   IF K=0 THEN 160
106   CY=CR* (1-DELY*(1-TR))
108   YCL=2*SPAN*GDEL/CY
110   IF DELY>0.75 THEN  115
112   YINC=0.1
113   GOTO 120
115   YINC=0.05
120   GAM=YCL*CY*VFPS/2
125   GAM=GAM*MULT
126   SGAM=SGAM+GAM*YINC*SPAN/2
130   PRINT"SPAN STATION=";DELY
132   PRINT"CY=";CY
134   PRINT"CLY="; YCL
140   PRINT"GAMMA=";GAM
142   PRINT" "
143   M=M+1
144   GOTO 91
160   PRINT" "
162   PRINT"CL/RADIAN=";RCL
164   PRINT"LIFT CURVE SLOPE=";SLC
165   PRINT"CT=";CT
166   AVGM=SCAM/(Span/2)
170   DATA 0.05,0.379,0.15,0.375,0.25,0.365
171   DATA 0.35,0.353,0.45,0.337,0.55,0.319
172   DATA 0.65,0.292,0.75,0.263,0.825,0.299
173   DATA 0.875,0.198,0.925,0.161,0.975,0.09, 1, 0
176   PRINT"AVG GAMMA=";AVGM
200   STOP
```

BASIC SPAN LOADING ANALYSIS

OUTPUT LISTING SPNLA

```
18 WT=13080

RUN
1071 SPAN LOADING AN
ALYSIS
FLAP SPAN=? 1
SPEED COMPUTATION=?
1
SPEED= 205.066196
SPAN=? 51.116
TAPER RATIO=? .667
ASPECT RATIO=? 8
CR= 7.67512199
SPAN STATION= .05
CY= 7.54733121
CLY= 5.13372568
GAMMA= 658.096692

SPAN STATION= .15
CY= 7.29174[illegible]5
CLY= 5.25758588
GAMMA= 651.15108

SPAN STATION= .25
CY= 7.03616809
CLY= 5.30326729
GAMMA= 633.787051

SPAN STATION= .35
CY= 6.78058[illegible]
CLY= 5.32223[illegible]
GAMMA= [illegible]95.216

SPAN STATION= .45
CY= 6.525[illegible]
CLY= 5.2[illegible]
GAMMA= [illegible]77

SPAN STATION= .55
CY= 6.2694234
CLY= 5.20175555
GAMMA= 553.912518

SPAN STATION= .65
CY= 6.01384184
CLY= 4.96383923
GAMMA= 507.029641

SPAN STATION= .75
CY= [illegible].75826027
CLY= [illegible].66929[illegible]02
GAMMA= 456.6[illegible]958

SPAN STATION= .825
CY= 5.5665741
CLY= 4.20566179
GAMMA= 397.63626

SPAN STATION= .875
CY= 5.43878332
CLY= 3.72177651
GAMMA= 343.80777

SPAN STATION= .925
CY= 5.3109925[illegible]
CLY= 3.09911[illegible]6
GAMMA= 279.5[illegible]

SPAN STATION= .975
CY= 5.18320[illegible]
CLY= 1.77513[illegible]5
GAMMA= 156.27[illegible]

CL/RADIAN=
 4.8293694
LIFT CURVE SLOPE=
 .0842821886
CT= 5.11930637
AVG GAMMA=
 524.74095
 BREAK IN 200

PRINT .002378*51.116
 5524.74*205.1
 137735.604

PRINT .002378*524.74
 51.116*205.1
 13082.1325
```

BASIC program for SPAN LOADING ANALYSIS

file name="SPNLB"

This version of the span loading analysis program is the same as SPNLA except for the following statements:

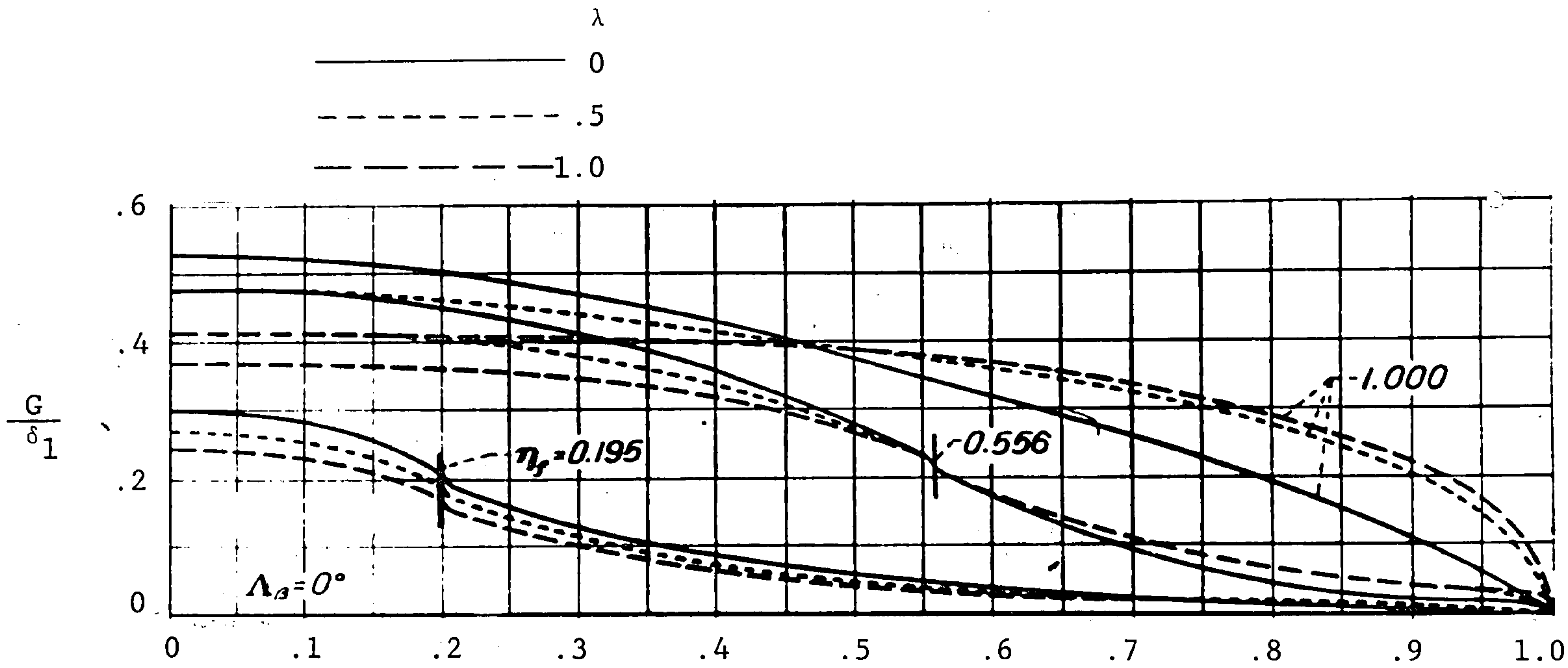
```
17    INPUT "VFPS="; VFPS
18    INPUT "WEIGHT="; WT.
20    INPUT "WING AREA ="; AREA
22    INPUT "DENSITY="; RHO
24    INPUT "LIFT COEFF="; CL
```

All succeeding statements are the same as SPNLA.

COMPUTER OUTPUT LISTING
for BASIC Span Loading Analysis

file name="SPNLB"

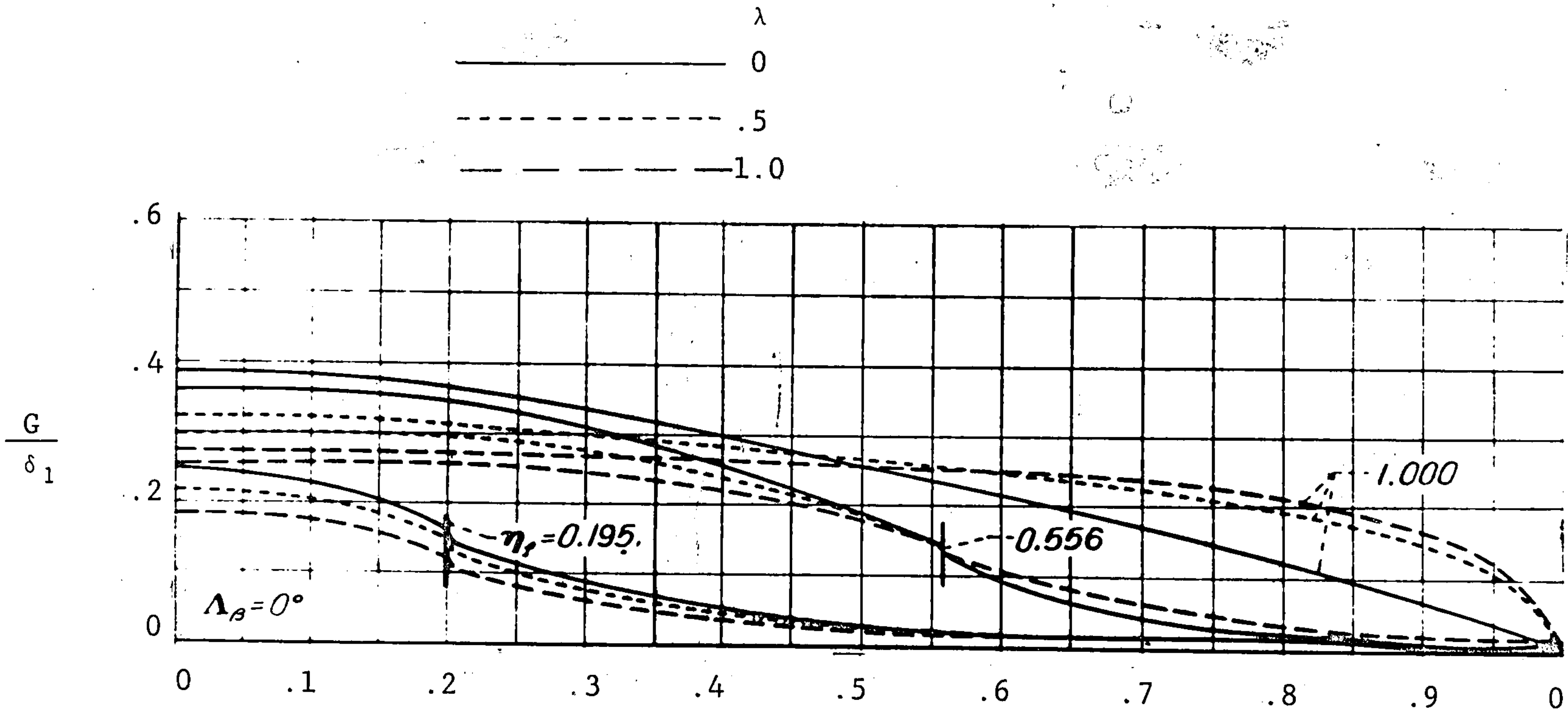
```
RUN
1071 SPAN LOADING AN
ALYSIS
FLAP SPAN=? 1
SPEED COMPUTATION=?
1
VFPS=? 139
WEIGHT=? 6000
WING AREA=? 327
DENSITY=? .002378
LIFT COEFF=? .8
SPEED= 138.888353
SPAN=? 51.116
TAPER RATIO=? .667
ASPECT RATIO=? 8
CR= 7.67512199
SPAN STATION= .05
CY= 7.54733121
CLY= 5.13372568
GAMMA= 445.719321

SPAN STATION= .15
CY= 7.29174965
CLY= 5.25758588
GAMMA= 441.01516

SPAN STATION= .25
CY= 7.03616809
CLY= 5.30326729
GAMMA= 429.254755

SPAN STATION= .35
CY= 6.78058653
CLY= 5.32223811
GAMMA= 415.14227

SPAN STATION= .45
CY= 6.52500496
CLY= 5.28002419
GAMMA= 396.325624

SPAN STATION= .55
CY= 6.2694234
CLY= 5.20175555
GAMMA= 375.156896

SPAN STATION= .65
CY= 6.01384184
CLY= 4.96383923
GAMMA= 343.403804

SPAN STATION= .75
CY= 5.75826027
CLY= 4.66929502
GAMMA= 309.298632

SPAN STATION= .825
CY= 5.5665741
CLY= 4.20566179
GAMMA= 269.31325

SPAN STATION= .875
CY= 5.43878332
CLY= 3.72177651
GAMMA= 232.856004

SPAN STATION= .925
CY= 5.31099254
CLY= 3.09911036
GAMMA= 189.3425

SPAN STATION= .975
CY= 5.18320176
CLY= 1.77513445
GAMMA= 105.843638


CL/RADIAN=
 4.8293694
LIFT CURVE SLOPE=
 .0842821886
CT= 5.11930637
AVG GAMMA=
 355.399417
BREAK IN  200
```



Spanwise load distribution factor, $\frac{G}{\delta_1}$, per radian.

Aspect ratio = 6.0

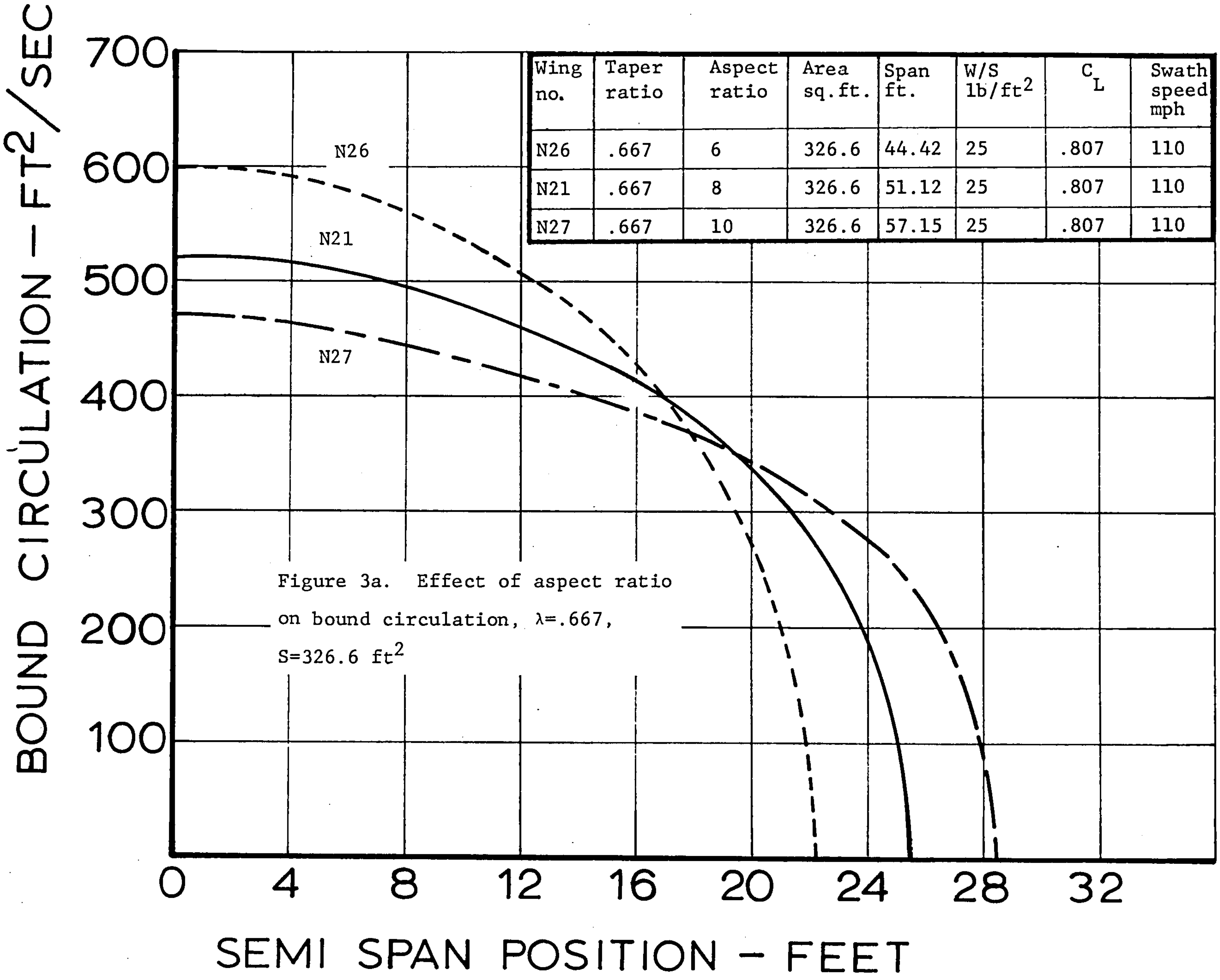
FIGURE 1.



Spanwise load distribution factor, $\frac{G}{\delta_1}$, per radian.

Aspect ratio = 10.0

FIGURE 2



Wing no.	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N26	.667	6	326.6	44.42	25	.807	110
N21	.667	8	326.6	51.12	25	.807	110
N27	.667	10	326.6	57.15	25	.807	110

Figure 3a. Effect of aspect ratio on bound circulation, λ=.667, S=326.6 ft^2

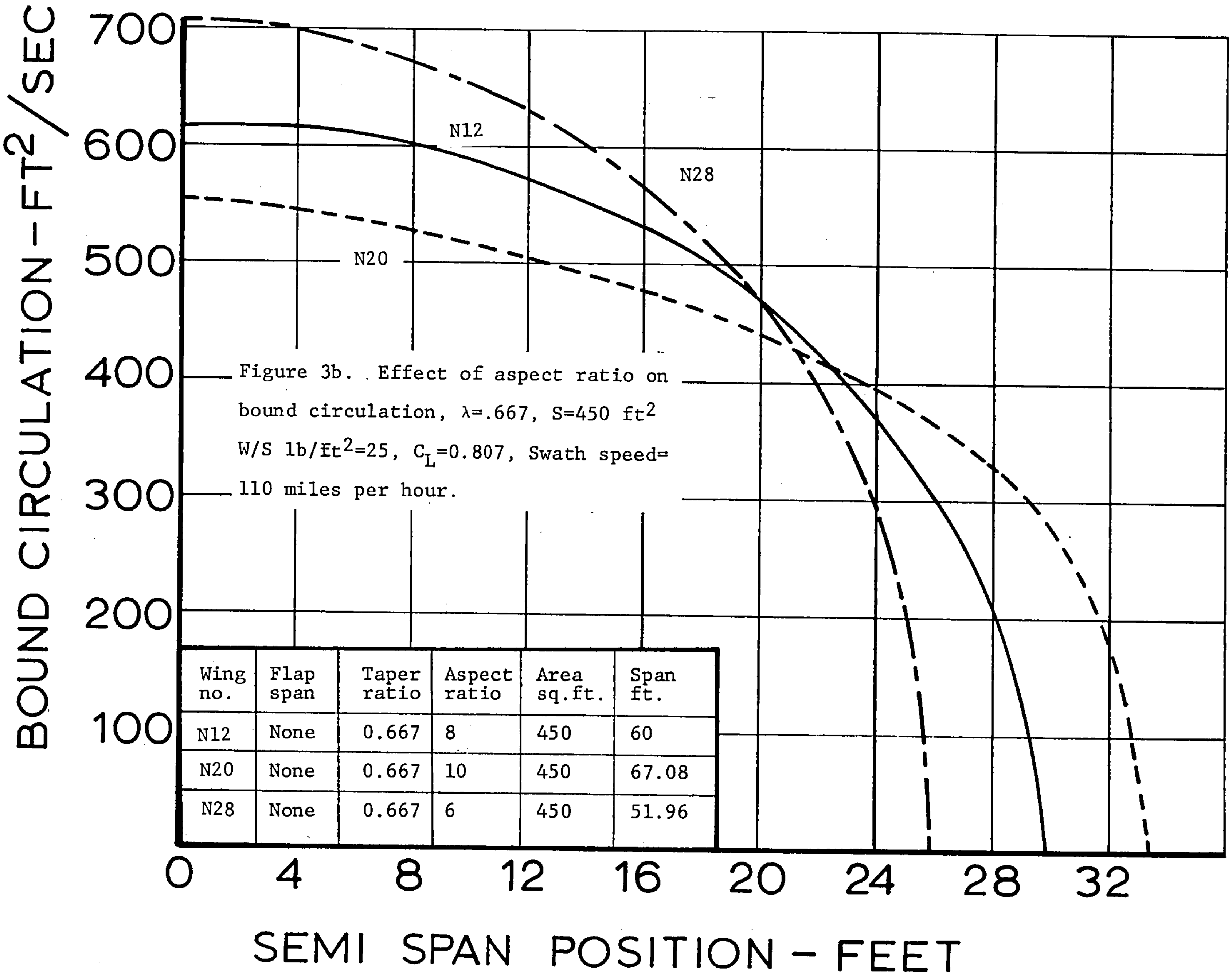
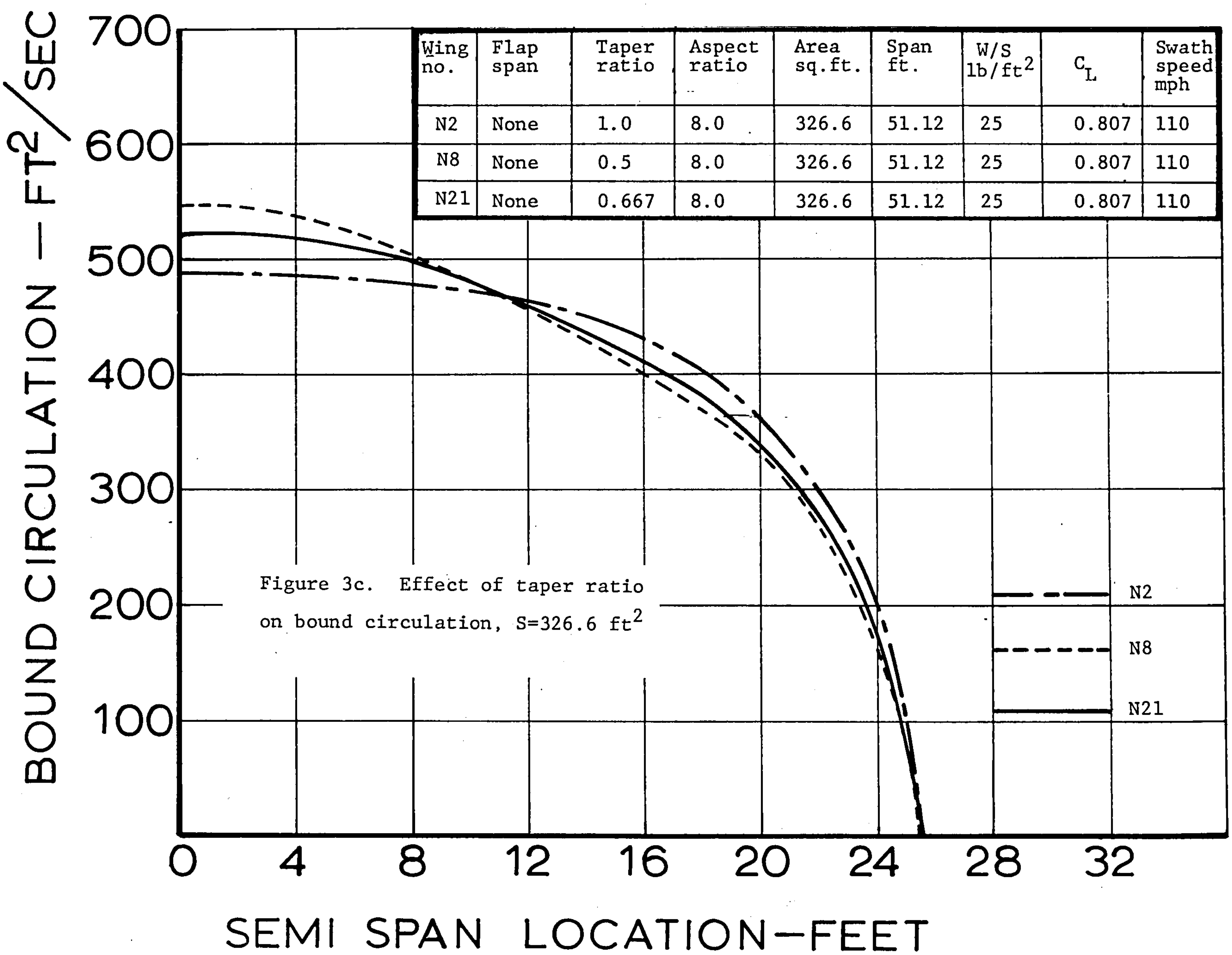


Figure 3b. Effect of aspect ratio on bound circulation, λ=.667, S=450 ft^2 W/S lb/ft^2=25, C_L=0.807, Swath speed= 110 miles per hour.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.
N12	None	0.667	8	450	60
N20	None	0.667	10	450	67.08
N28	None	0.667	6	450	51.96



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N2	None	1.0	8.0	326.6	51.12	25	0.807	110
N8	None	0.5	8.0	326.6	51.12	25	0.807	110
N21	None	0.667	8.0	326.6	51.12	25	0.807	110

Figure 3c. Effect of taper ratio on bound circulation, $S=326.6\ ft^2$

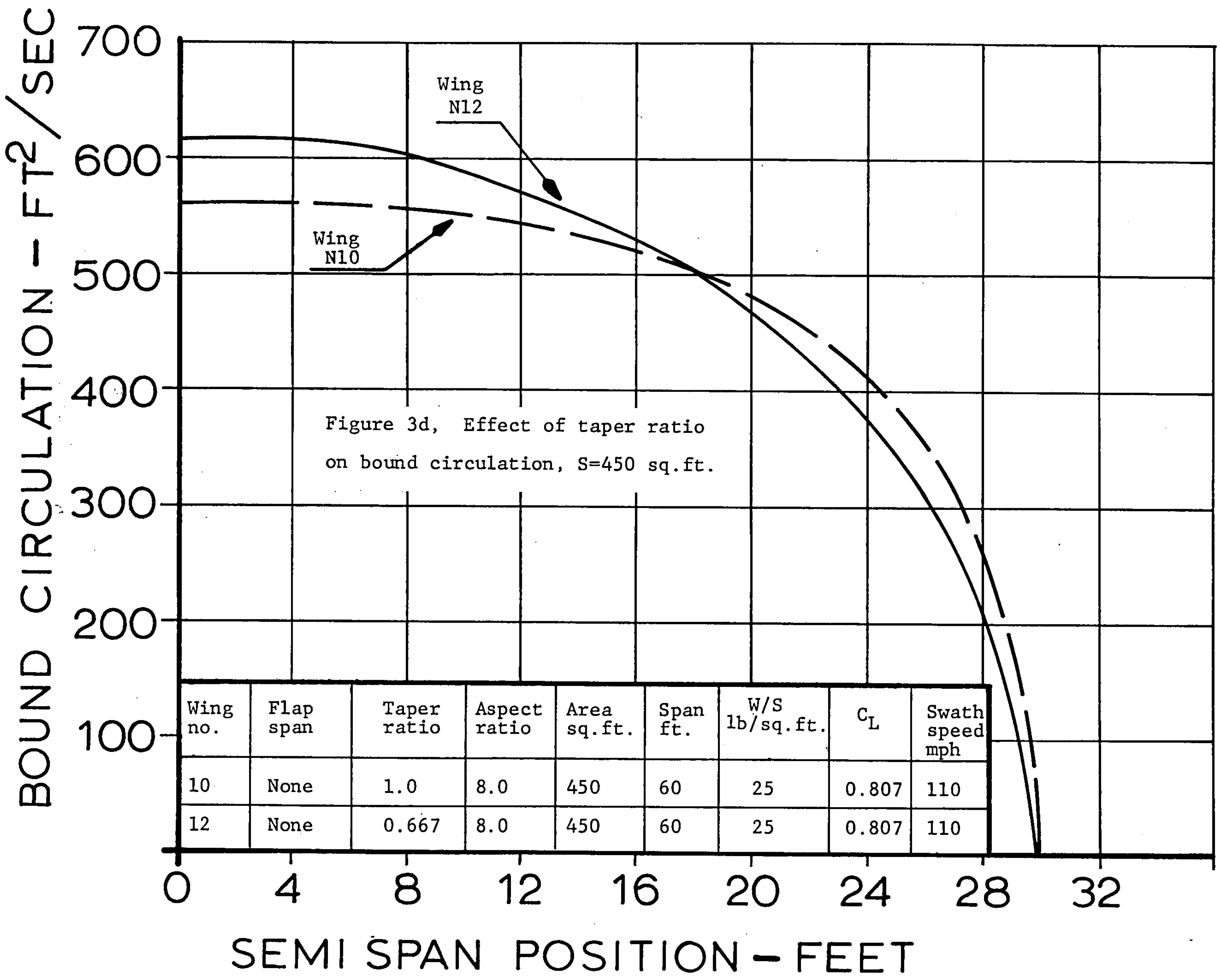
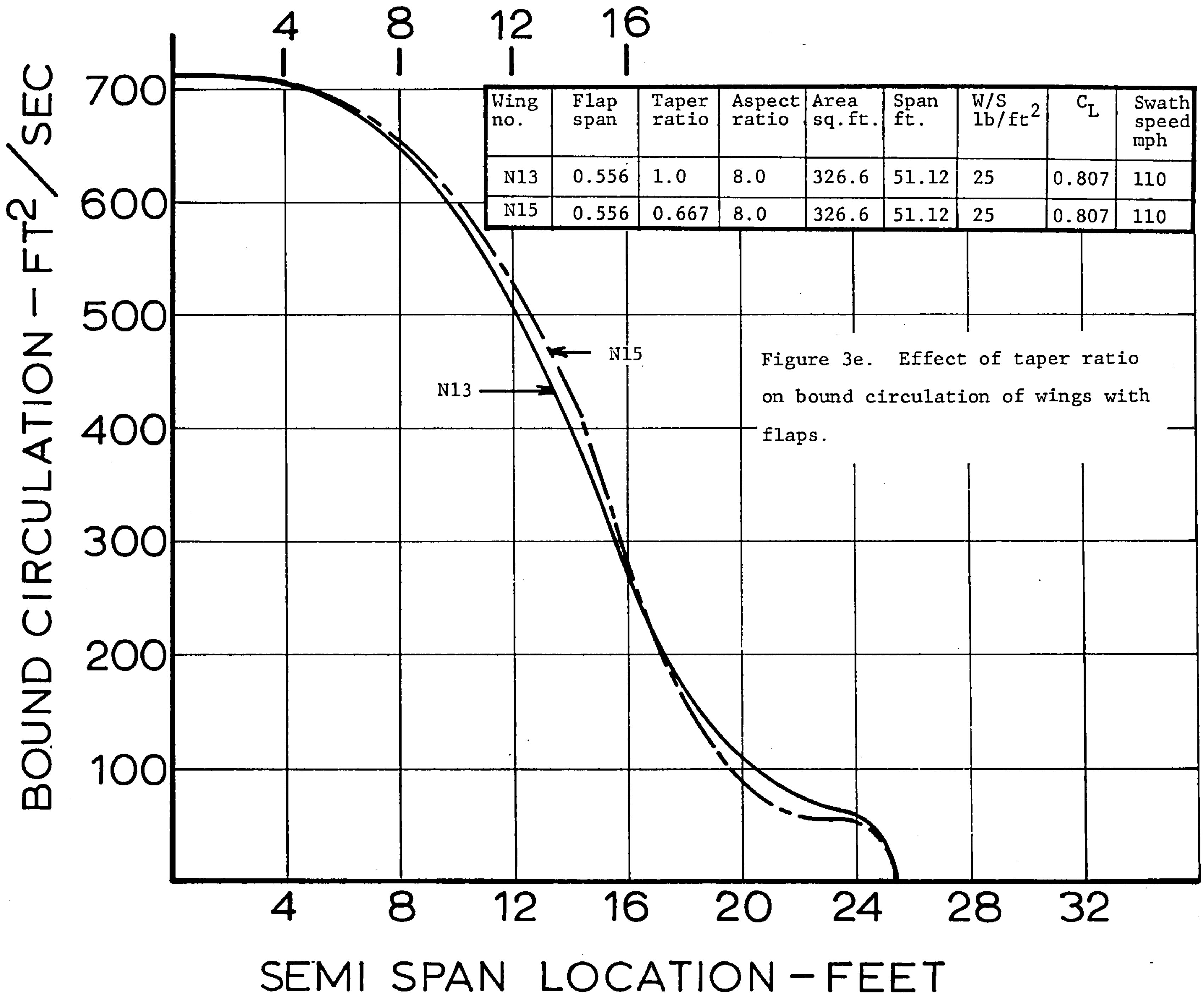


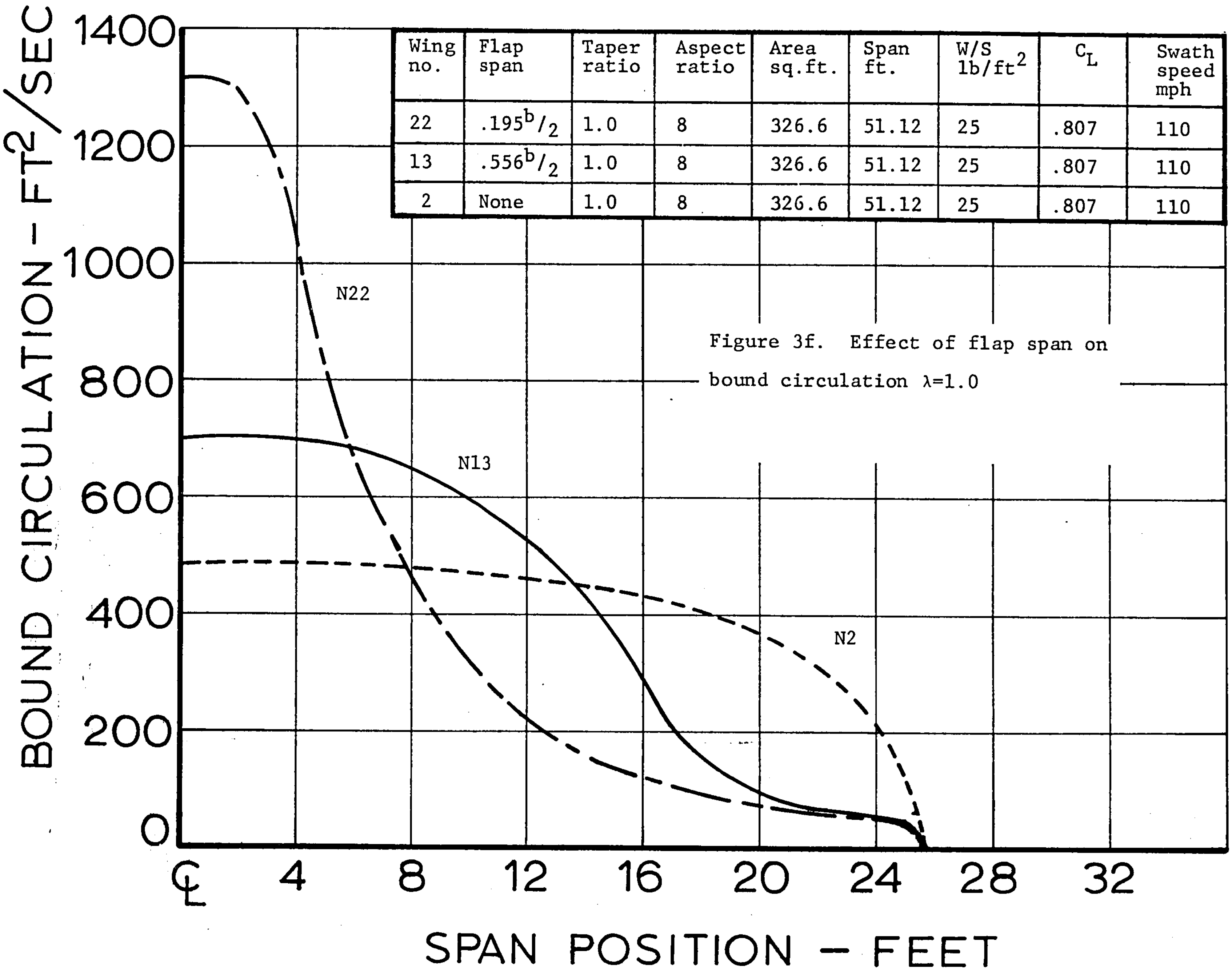
Figure 3d, Effect of taper ratio on bound circulation, S=450 sq.ft.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/sq.ft.	C_L	Swath speed mph
10	None	1.0	8.0	450	60	25	0.807	110
12	None	0.667	8.0	450	60	25	0.807	110



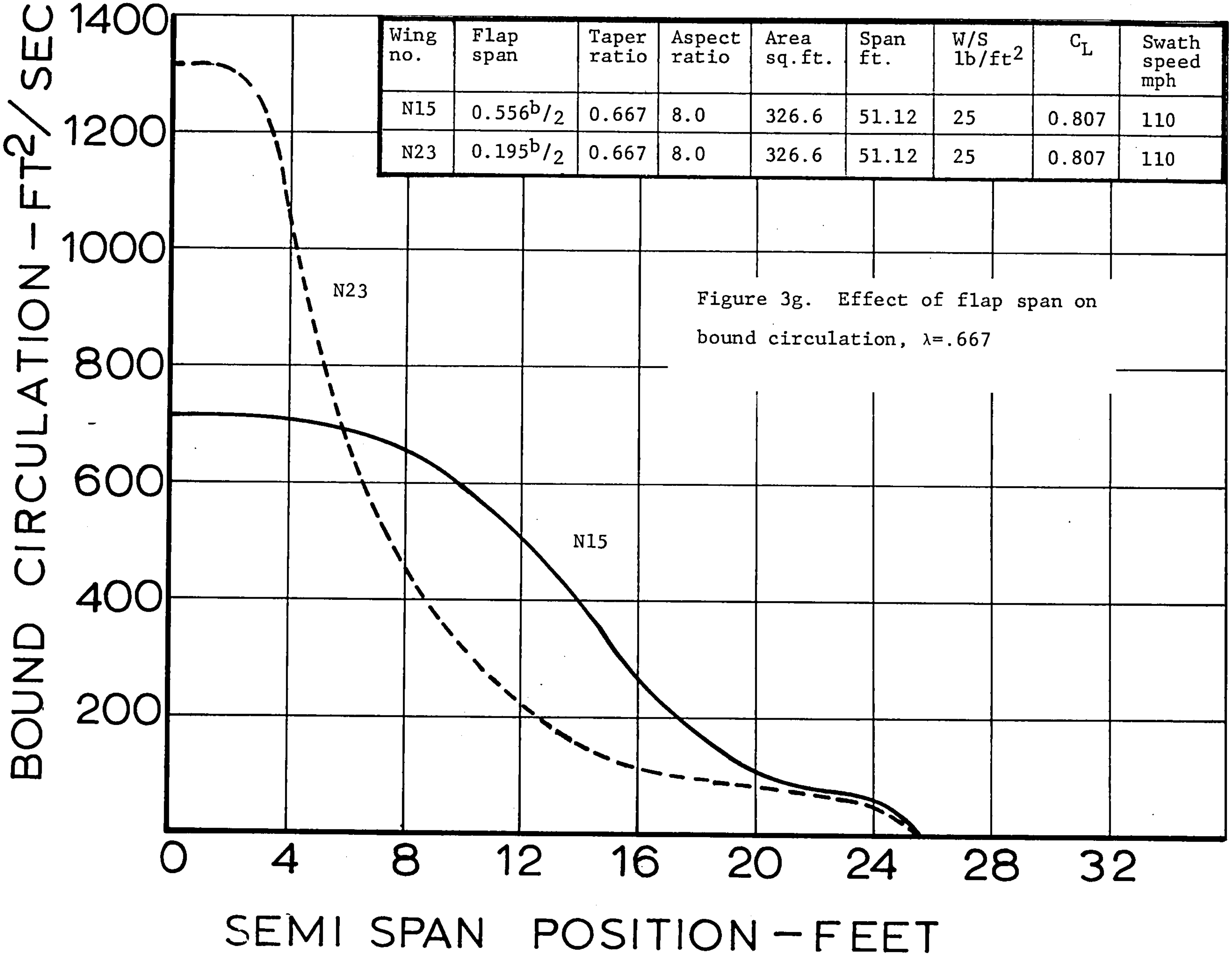
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N13	0.556	1.0	8.0	326.6	51.12	25	0.807	110
N15	0.556	0.667	8.0	326.6	51.12	25	0.807	110

Figure 3e. Effect of taper ratio on bound circulation of wings with flaps.



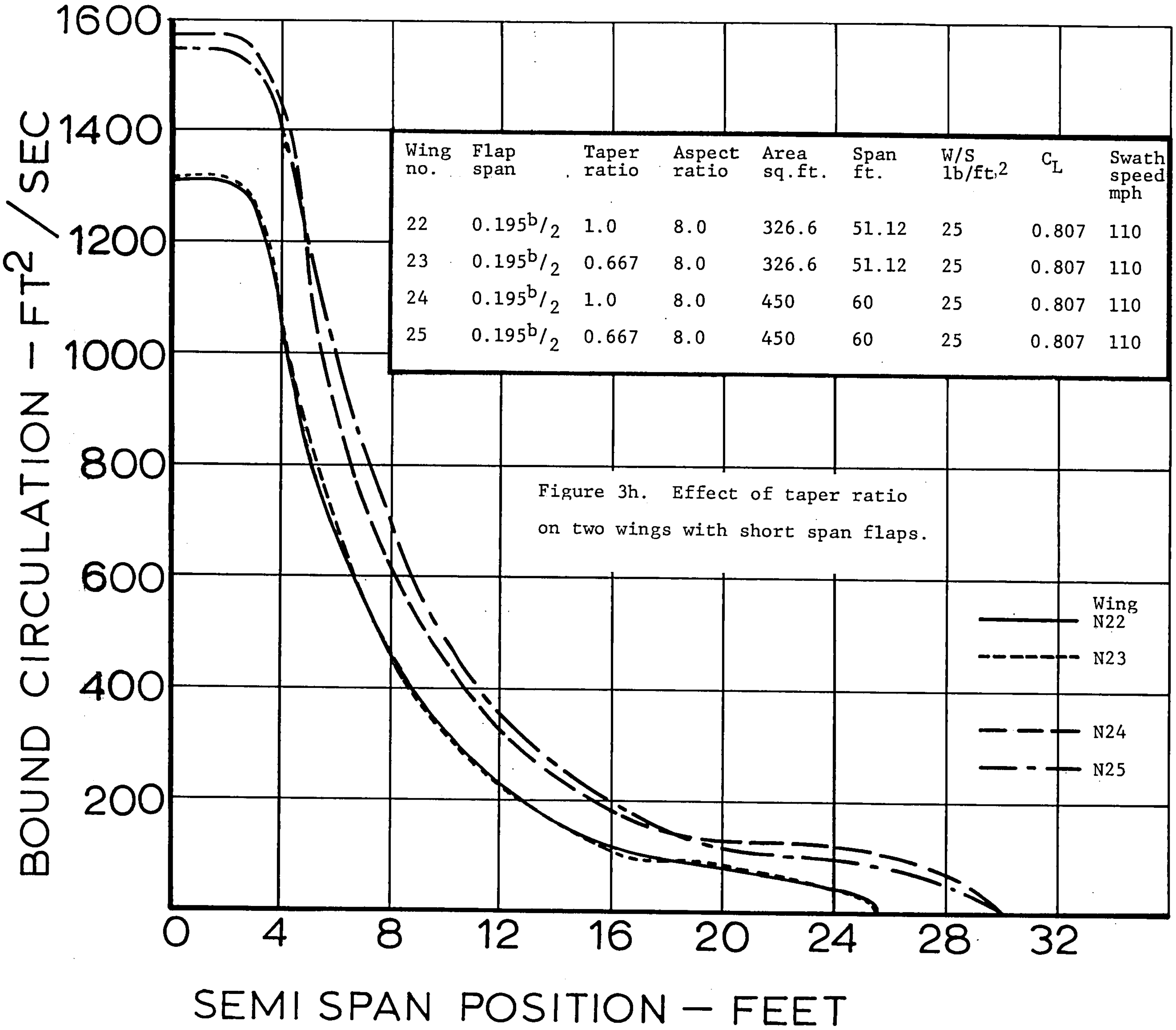
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
22	$.195^b/_2$	1.0	8	326.6	51.12	25	.807	110
13	$.556^b/_2$	1.0	8	326.6	51.12	25	.807	110
2	None	1.0	8	326.6	51.12	25	.807	110

Figure 3f. Effect of flap span on bound circulation λ=1.0



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N15	$0.556^b/_2$	0.667	8.0	326.6	51.12	25	0.807	110
N23	$0.195^b/_2$	0.667	8.0	326.6	51.12	25	0.807	110

Figure 3g. Effect of flap span on bound circulation, λ=.667



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft.^{2}	C_L	Swath speed mph
22	$0.195^{b}/_{2}$	1.0	8.0	326.6	51.12	25	0.807	110
23	$0.195^{b}/_{2}$	0.667	8.0	326.6	51.12	25	0.807	110
24	$0.195^{b}/_{2}$	1.0	8.0	450	60	25	0.807	110
25	$0.195^{b}/_{2}$	0.667	8.0	450	60	25	0.807	110

Figure 3h. Effect of taper ratio on two wings with short span flaps.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N23	0.195	0.667	8.0	326.6	51.116	25	0.807	110
N21	0	0.667	8.0	326.6	51.116	25	0.807	110
N31	0.805*	0.667	8.0	326.6	51.116	25	0.807	110

* Outboard

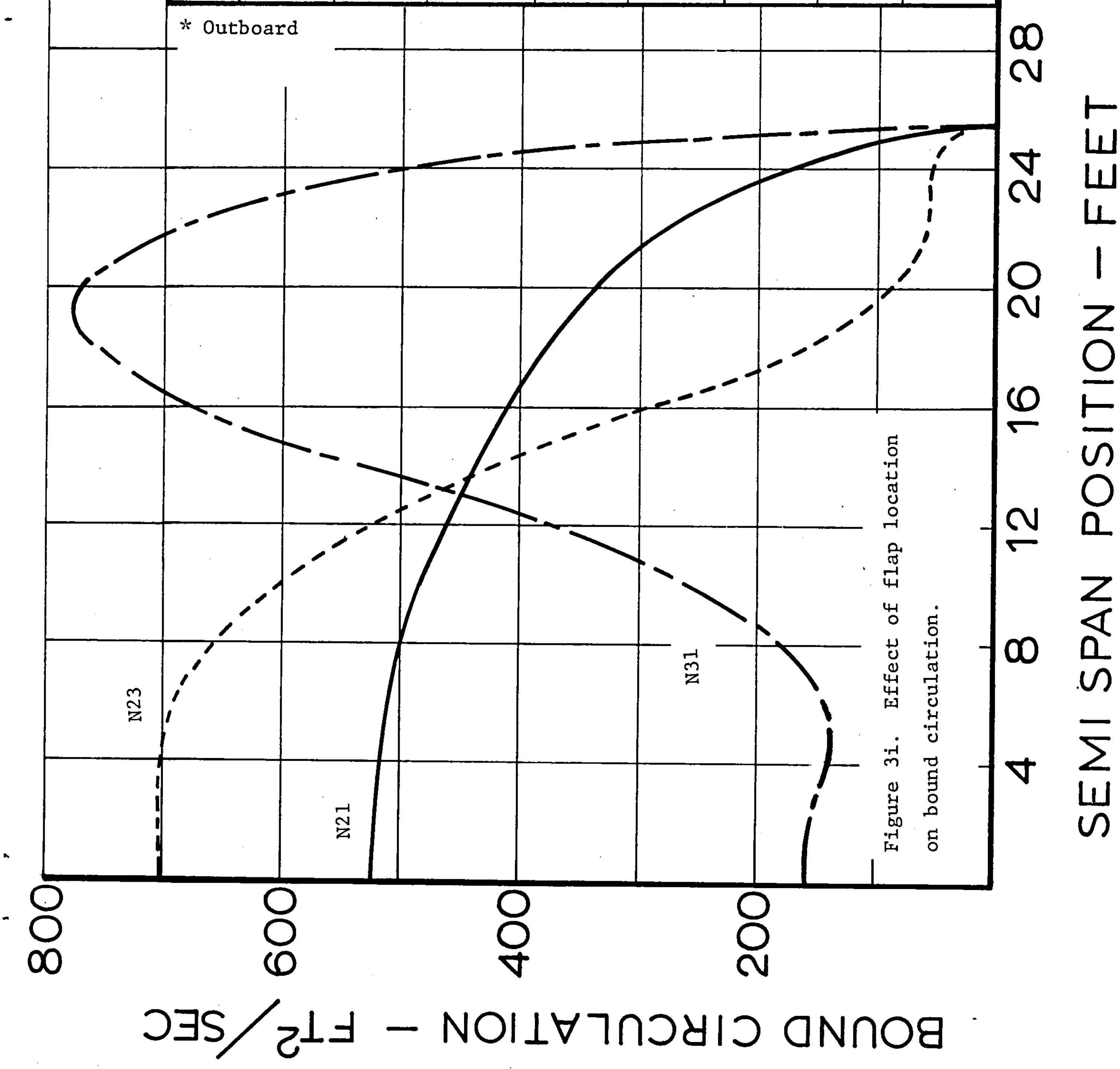


Figure 3i. Effect of flap location on bound circulation.

Wing no.	Outboard flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N21	0	0.667	8.0	326.6	51.116	25	0.807	110
N31	0.444	0.667	8.0	326.6	51.116	25	0.807	110
N32	0.805	0.667	8.0	326.6	51.116	25	0.807	110

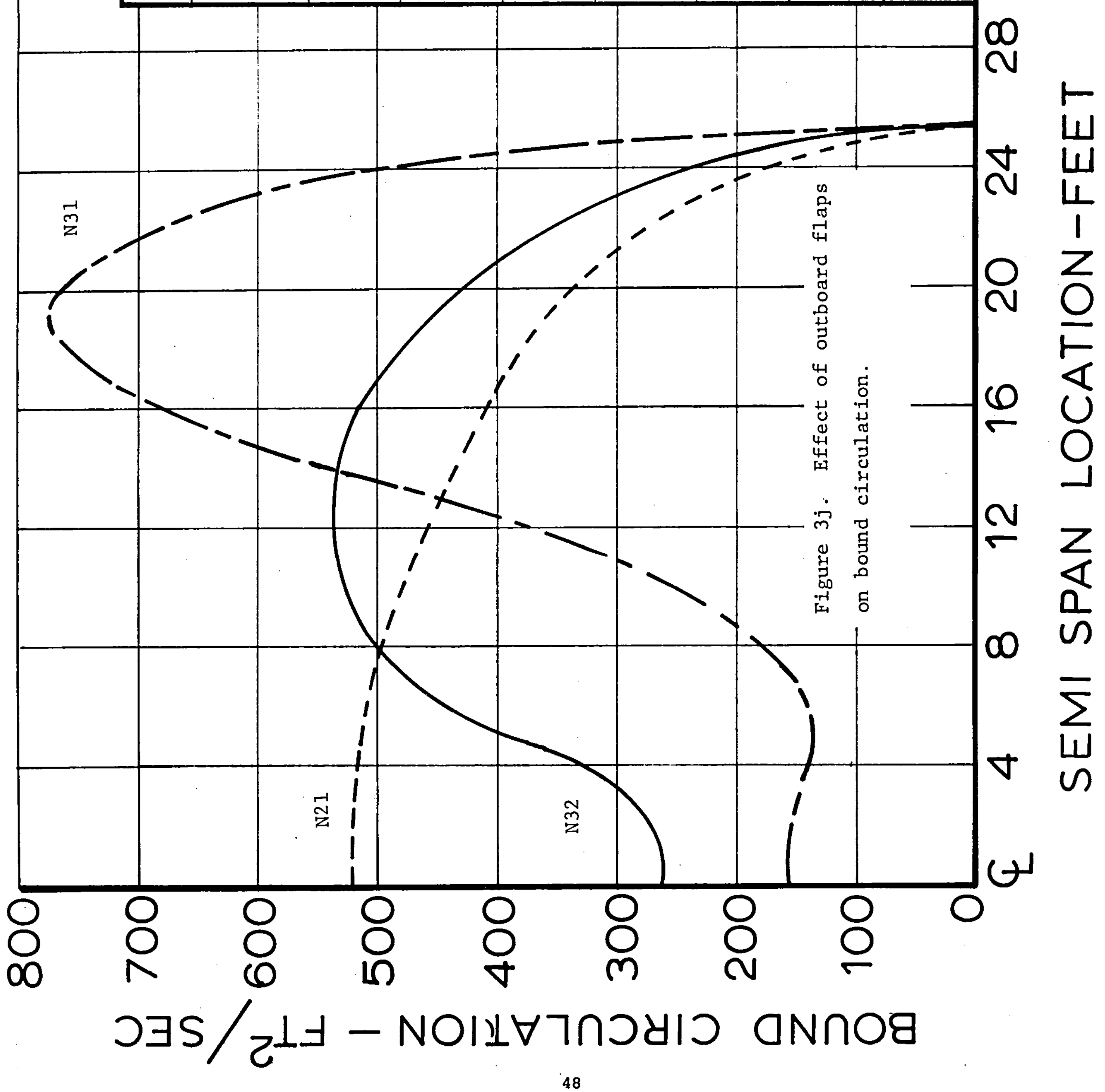
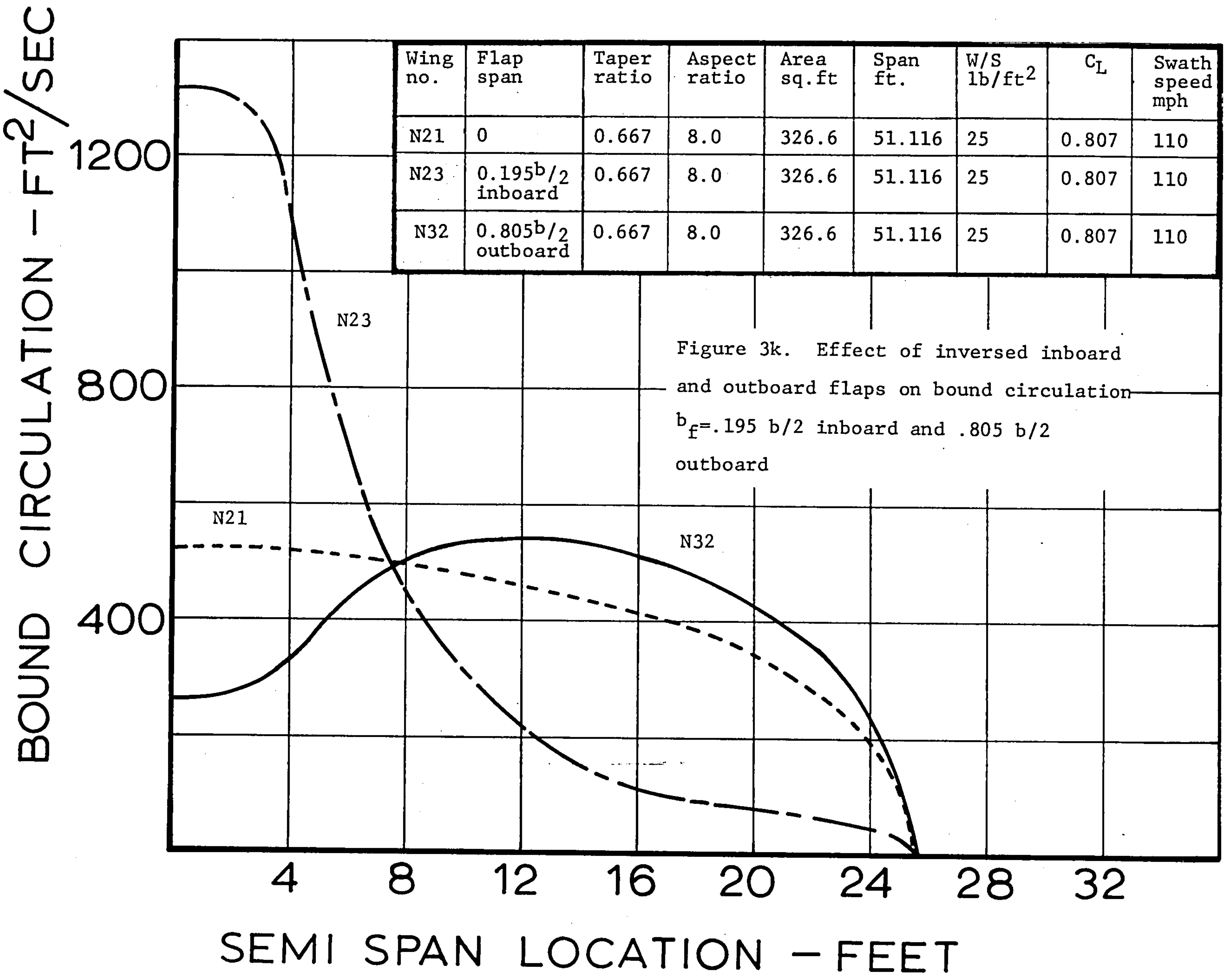


Figure 3j. Effect of outboard flaps on bound circulation.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N21	0	0.667	8.0	326.6	51.116	25	0.807	110
N23	0.195b/2 inboard	0.667	8.0	326.6	51.116	25	0.807	110
N32	0.805b/2 outboard	0.667	8.0	326.6	51.116	25	0.807	110

Figure 3k. Effect of inversed inboard and outboard flaps on bound circulation b_f=.195 b/2 inboard and .805 b/2 outboard

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N15	None	.667	8	326.6	51.12	25	.807	110
N21	$.556^b/_2$ inboard	.667	8	326.6	51.12	25	.807	110
N31	$.444^b/_2$ outboard	.667	8	326.6	51.12	25	.807	110

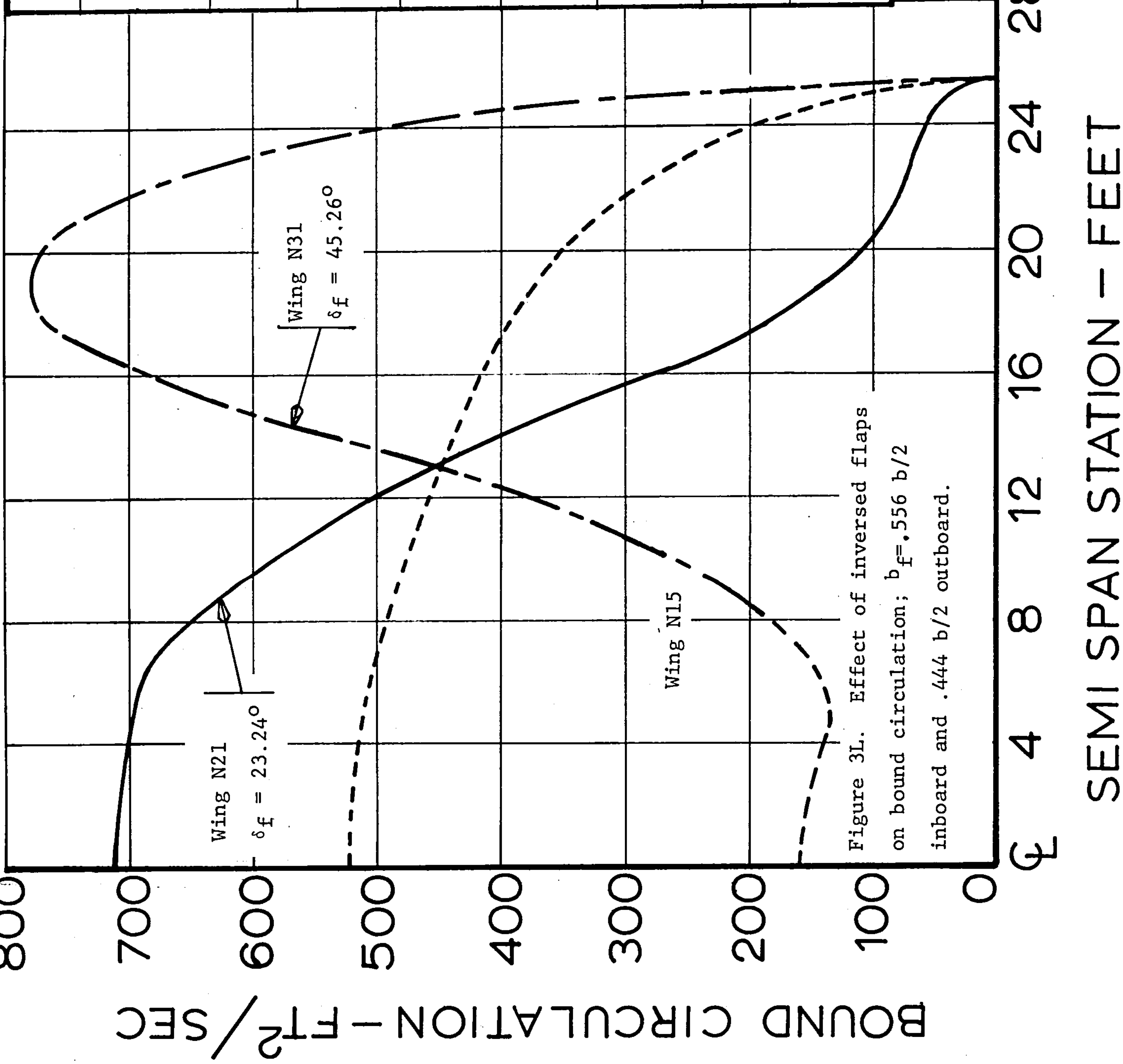


Figure 3L. Effect of inversed flaps on bound circulation; b_f=.556 b/2 inboard and .444 b/2 outboard.

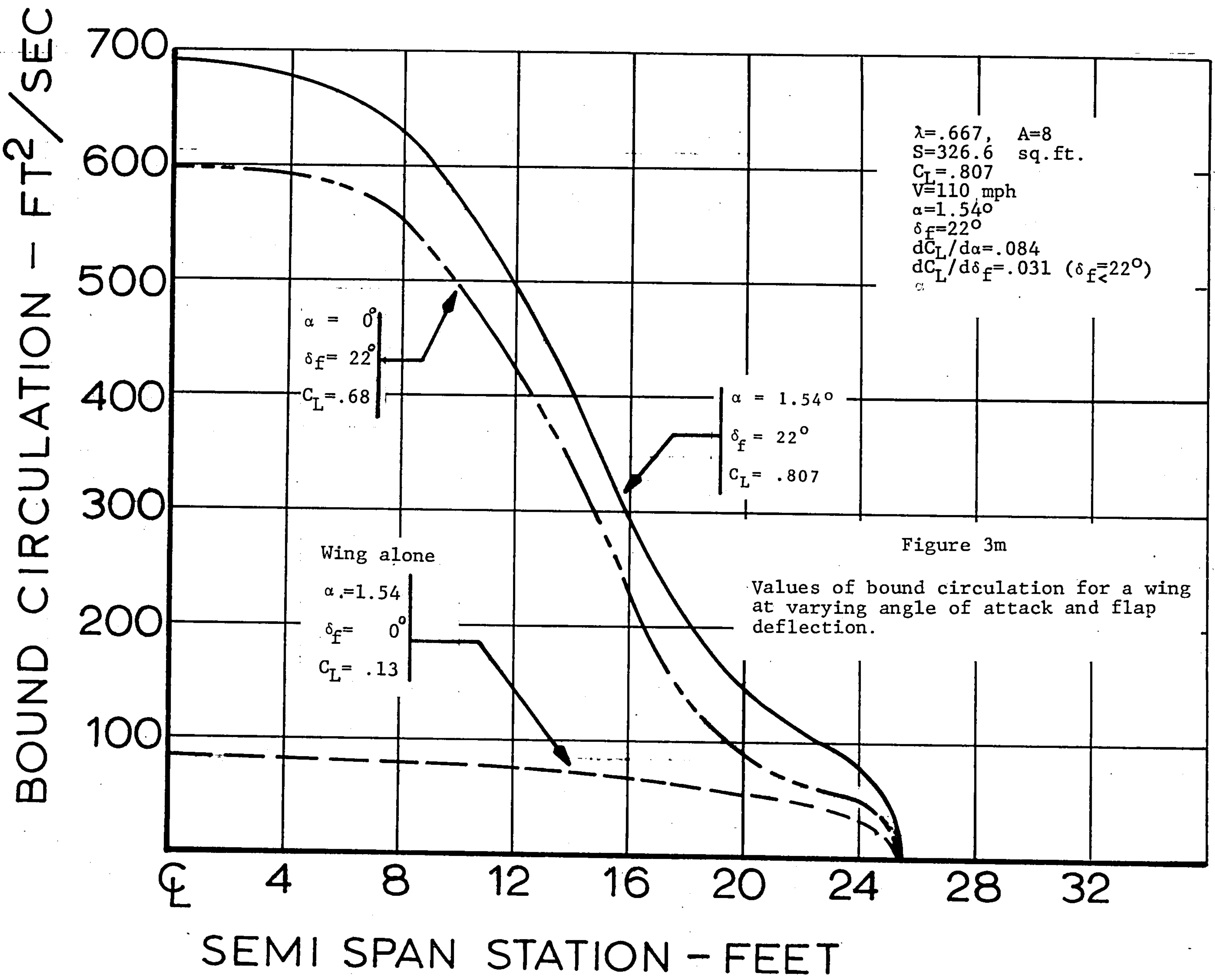
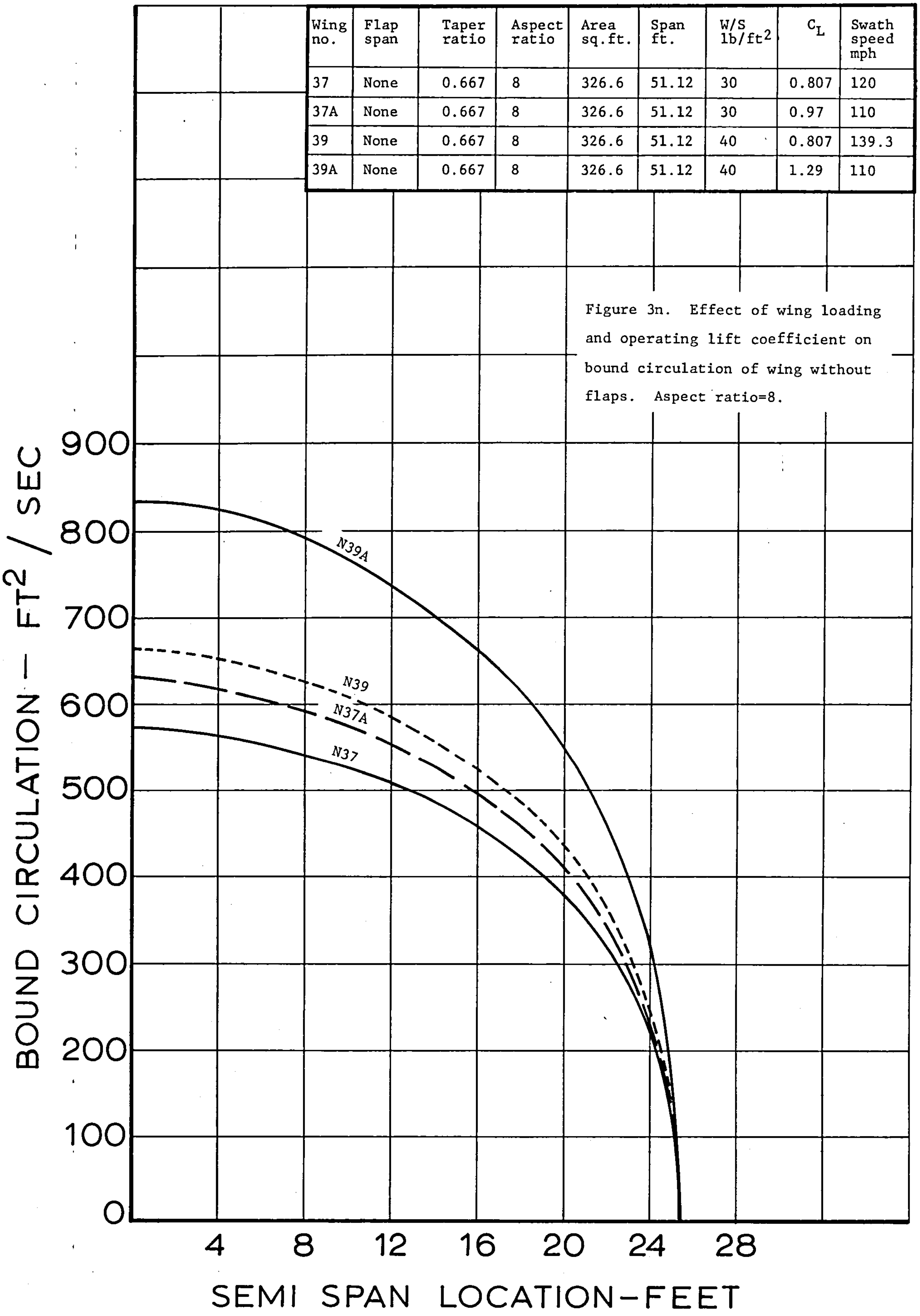


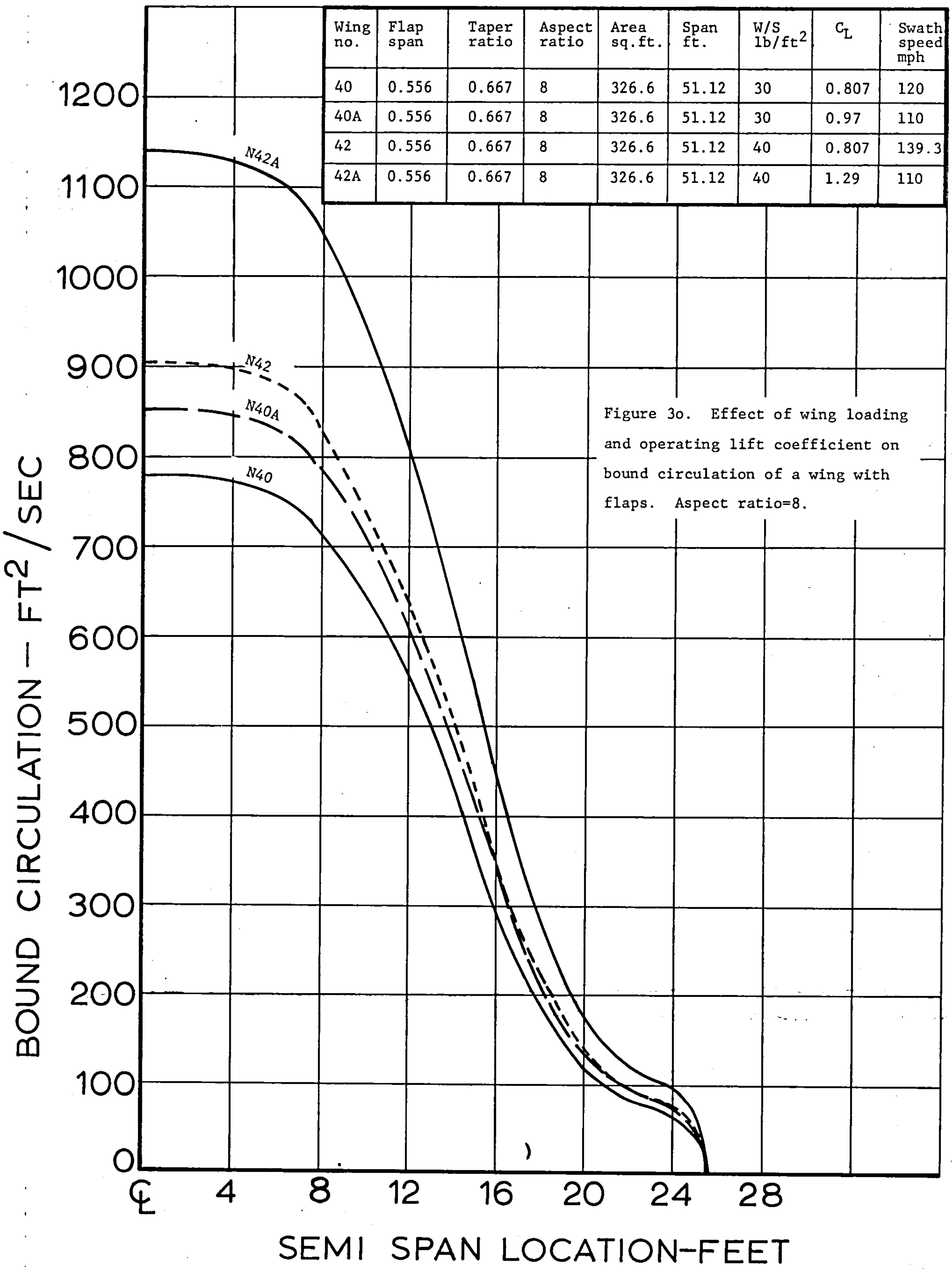
Figure 3m

Values of bound circulation for a wing at varying angle of attack and flap deflection.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
37	None	0.667	8	326.6	51.12	30	0.807	120
37A	None	0.667	8	326.6	51.12	30	0.97	110
39	None	0.667	8	326.6	51.12	40	0.807	139.3
39A	None	0.667	8	326.6	51.12	40	1.29	110

Figure 3n. Effect of wing loading and operating lift coefficient on bound circulation of wing without flaps. Aspect ratio=8.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
40	0.556	0.667	8	326.6	51.12	30	0.807	120
40A	0.556	0.667	8	326.6	51.12	30	0.97	110
42	0.556	0.667	8	326.6	51.12	40	0.807	139.3
42A	0.556	0.667	8	326.6	51.12	40	1.29	110

Figure 3o. Effect of wing loading and operating lift coefficient on bound circulation of a wing with flaps. Aspect ratio=8.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
43	None	0.667	6	326.6	51.12	30	0.807	120
43A	None	0.667	6	326.6	51.12	30	.97	110
45	None	0.667	6	326.6	51.12	40	0.807	139.3
45A	None	0.667	6	326.6	51.12	40	1.29	110

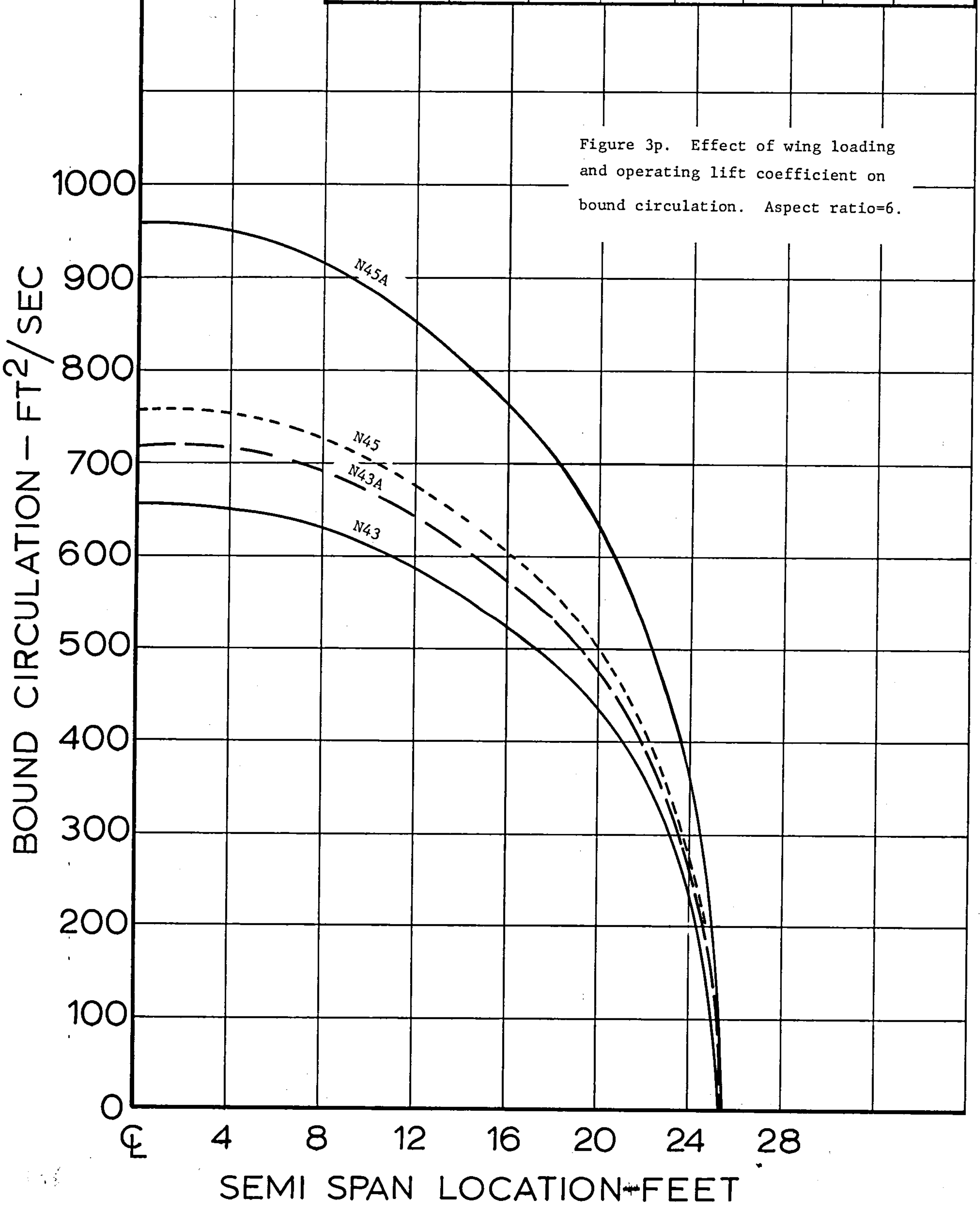
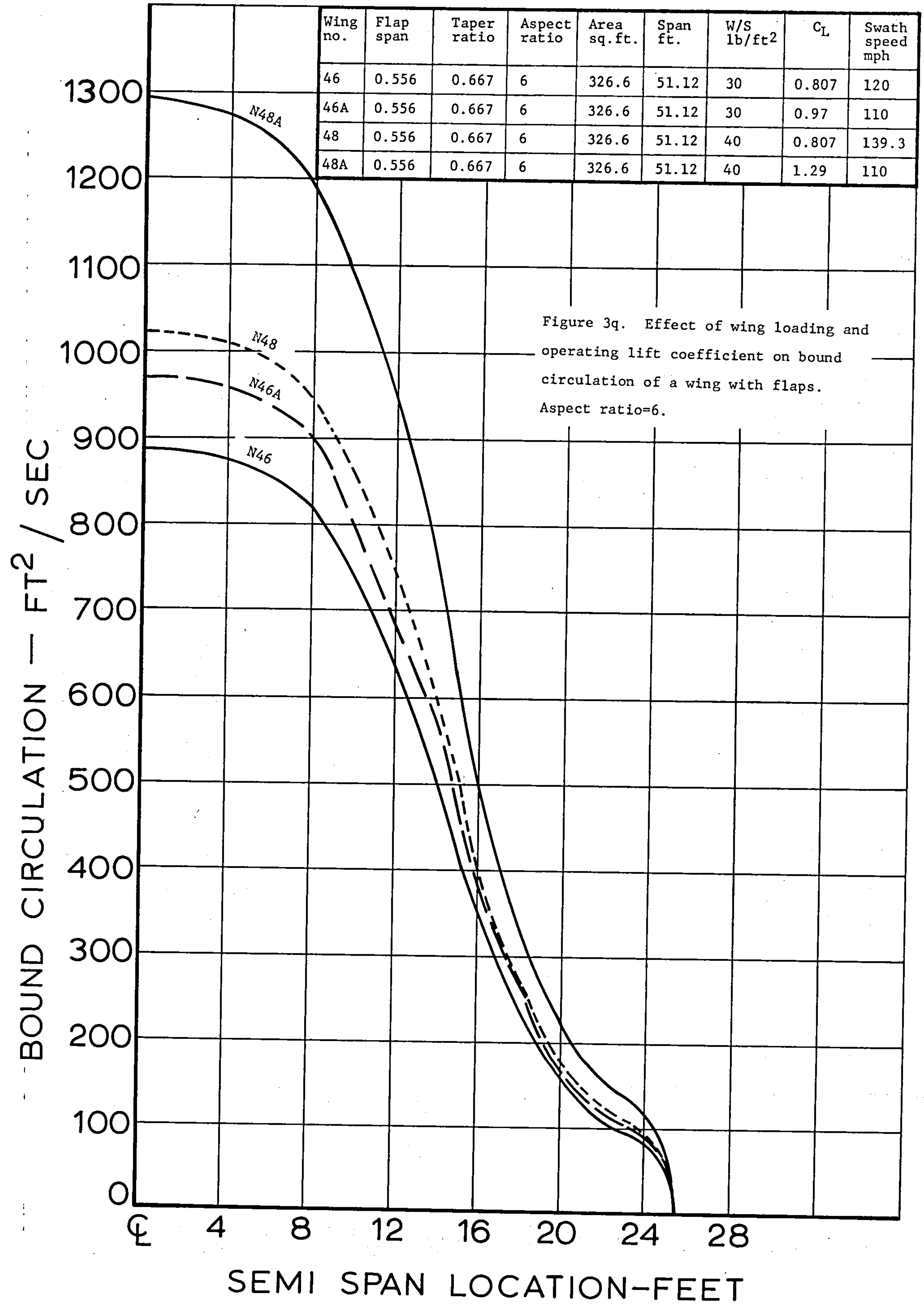


Figure 3p. Effect of wing loading and operating lift coefficient on bound circulation. Aspect ratio=6.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
46	0.556	0.667	6	326.6	51.12	30	0.807	120
46A	0.556	0.667	6	326.6	51.12	30	0.97	110
48	0.556	0.667	6	326.6	51.12	40	0.807	139.3
48A	0.556	0.667	6	326.6	51.12	40	1.29	110

Figure 3q. Effect of wing loading and operating lift coefficient on bound circulation of a wing with flaps. Aspect ratio=6.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N26	None	.667	6	326.6	44.42	25	.807	110
N21	None	.667	8	326.6	51.12	25	.807	110
N27	None	.667	10	326.6	57.15	25	.807	110

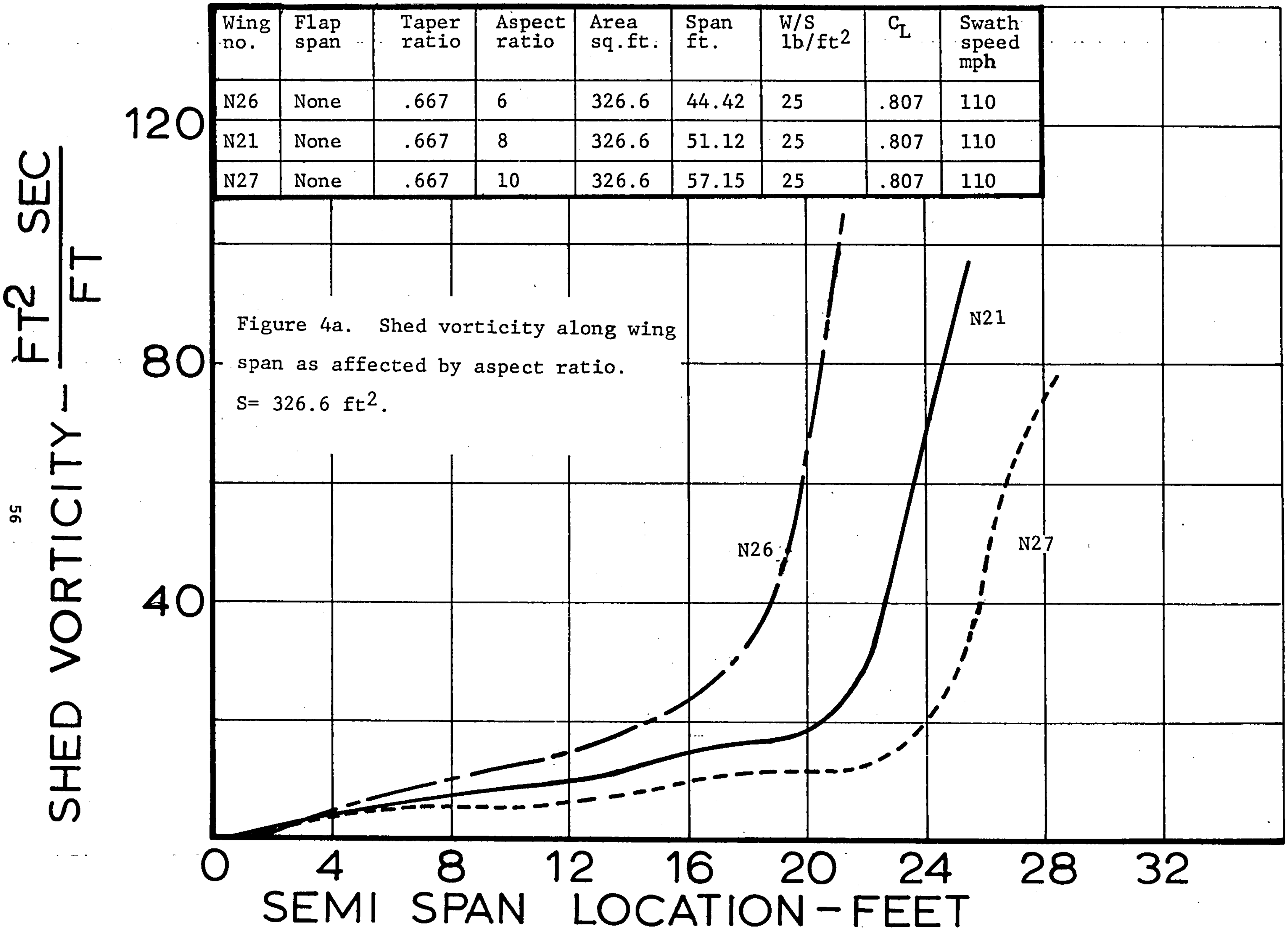
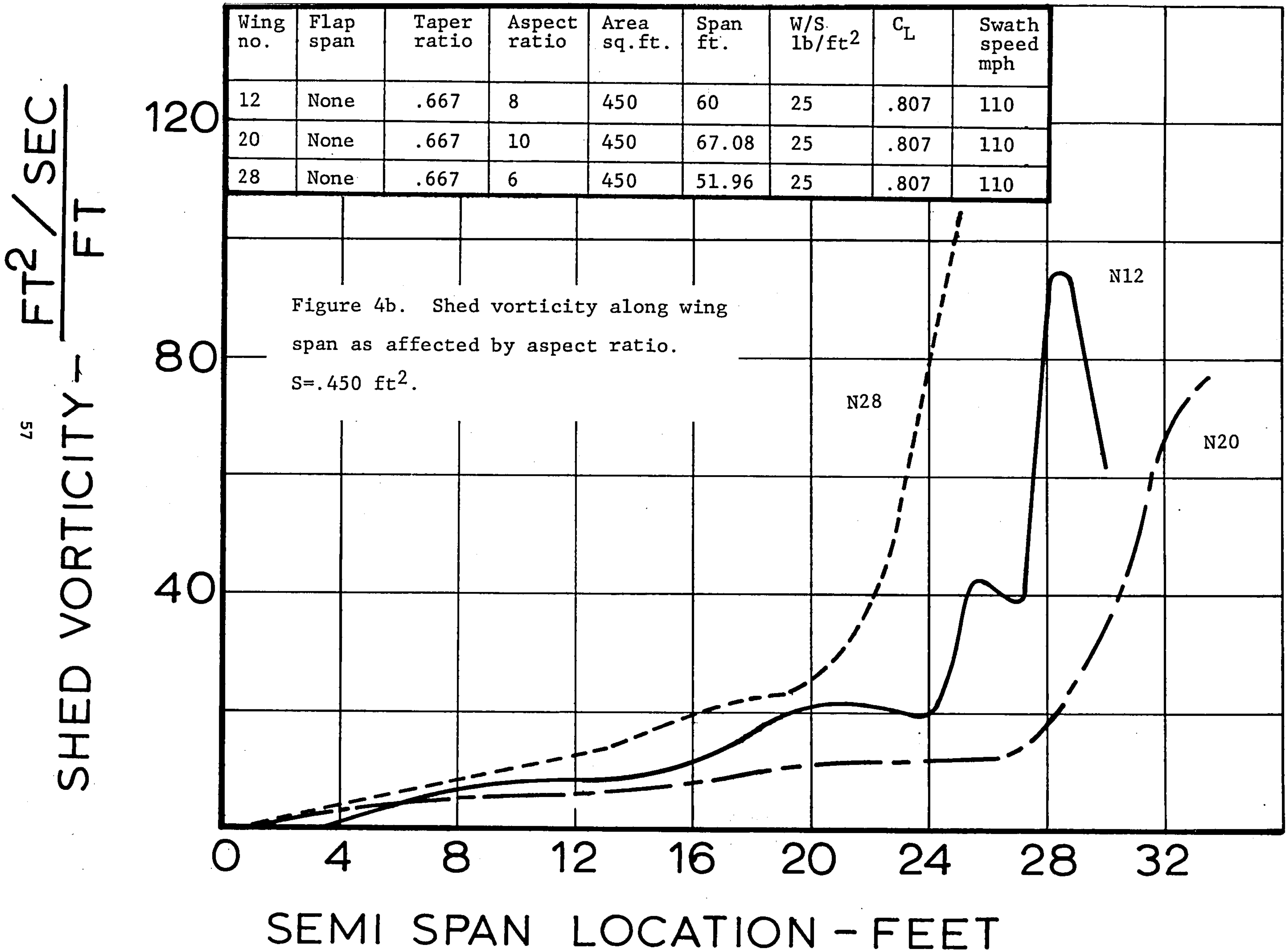
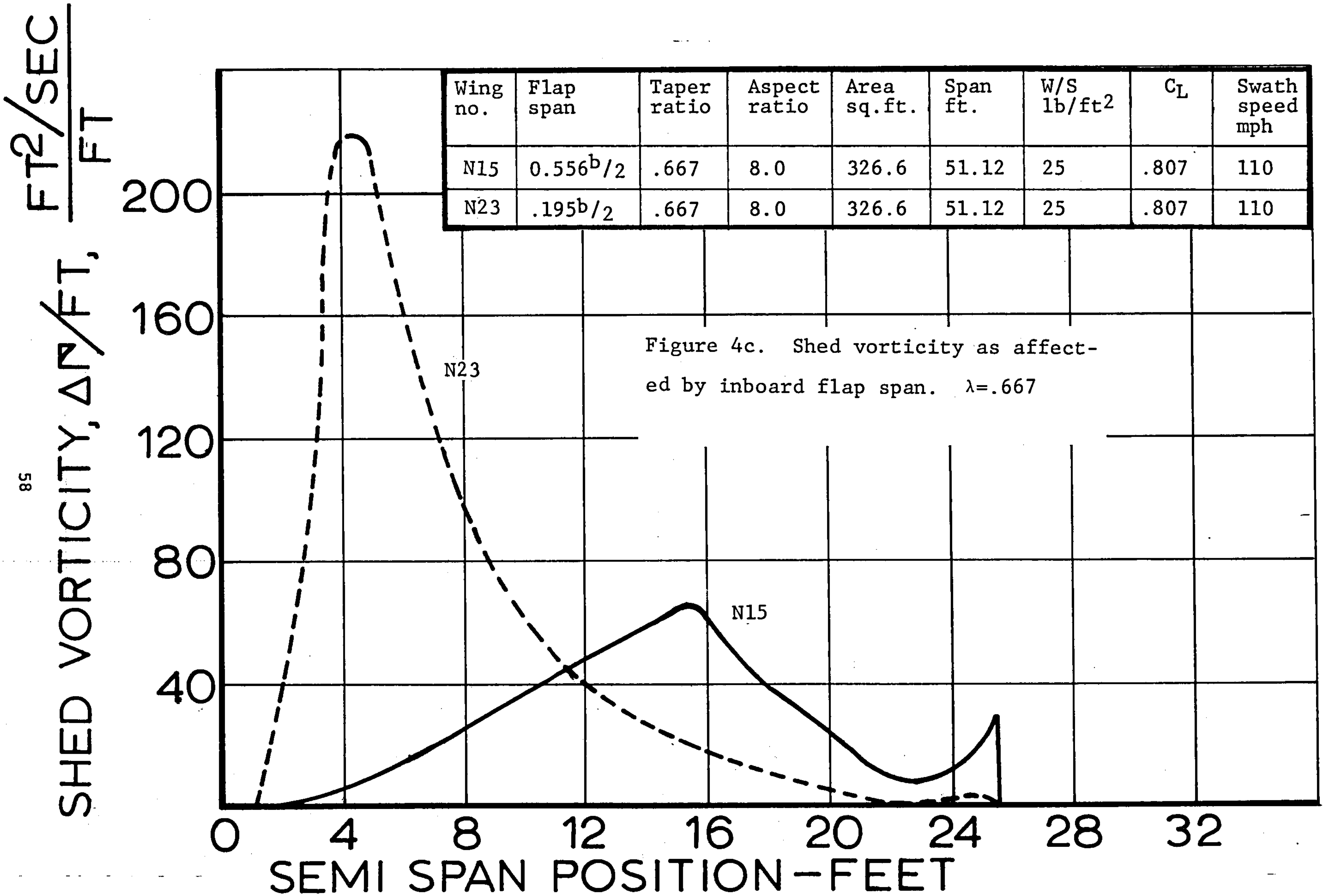


Figure 4a. Shed vorticity along wing span as affected by aspect ratio. S= 326.6 ft^2.



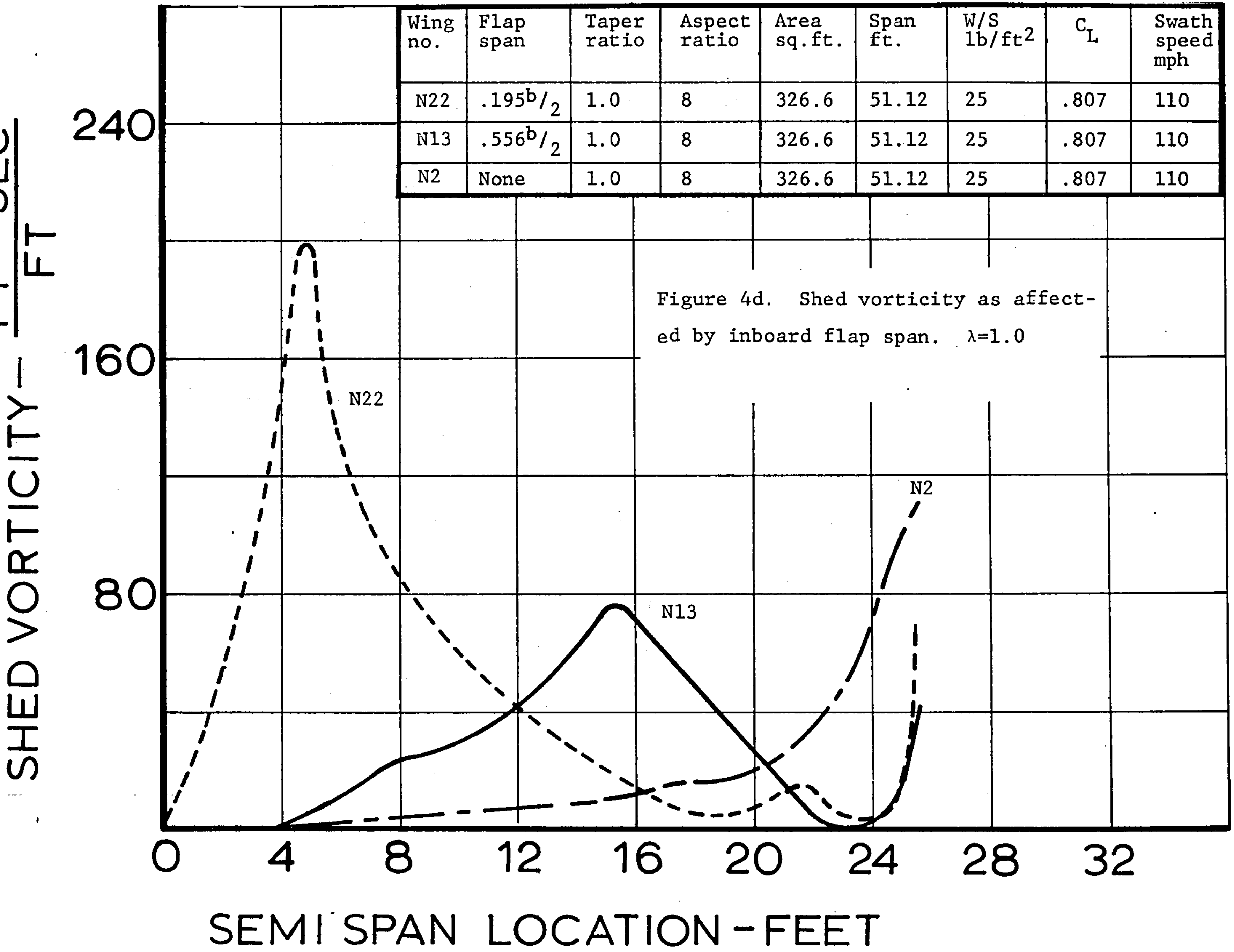
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
12	None	.667	8	450	60	25	.807	110
20	None	.667	10	450	67.08	25	.807	110
28	None	.667	6	450	51.96	25	.807	110

Figure 4b. Shed vorticity along wing span as affected by aspect ratio. S=.450 ft^2.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N15	$0.556^b/_2$	.667	8.0	326.6	51.12	25	.807	110
N23	$.195^b/_2$	.667	8.0	326.6	51.12	25	.807	110

Figure 4c. Shed vorticity as affected by inboard flap span. λ=.667



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N22	.195$^b/_2$	1.0	8	326.6	51.12	25	.807	110
N13	.556$^b/_2$	1.0	8	326.6	51.12	25	.807	110
N2	None	1.0	8	326.6	51.12	25	.807	110

Figure 4d. Shed vorticity as affected by inboard flap span. λ=1.0

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